PHILOSOPHY OF NATURE

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BY

MORITZ SCHLICK

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PREFACE

By the Editors

TWELVE YEARS have passed since Moritz Schlick, Professor of Philosophy at the University of Vienna, was murdered by a lunatic. He has left the stamp of his personality on the history of philosophy, not only in Austria, but in the whole world.

What is the reason for the deep and permanent impression made by Schlick on both his friends and pupils? His aim was not to develop a new system of philosophy, but to teach a scientific way of philosophizing, which his assistant, Frederick Waismann, described as being one of the most logical and radical attempts that has ever been undertaken, to overcome the cleavage in philosophical systems, and to attain a standpoint in philosophy which, while in itself not tendentious, yet consolidates all tendencies[1].

For a thinker with such an outlook, the task of explaining the relations between philosophy and the exact sciences, could not be neglected; and Schlick's "Allgemeine Erkenntnislehre"[2] gives his solution to the problem in a form to which he continued to adhere, even at a later period. The task of science, he maintained, is to obtain knowledge of reality; and the true achievements of science can neither be destroyed

nor altered by philosophy, "but the aim of philosophy is to interpret these achievements correctly, and to expound their deepest meaning. This interpretation is the ultimate, as well as the highest scientific task, and will always remain so".

As quite a young student at a secondary school (Realgymnasium) in his native city, Berlin, Schlick was already intensely interested in mathematics and science; and at the Universities of Heidelberg, Lausanne and Berlin, he chose physics as his chief subject. His dissertation for Max Planck was on the "Reflection of Light"; and in 1904, he took his doctor's degree at the University of Berlin.

At a very early age, Schlick's interests already extended beyond the domain of the exact sciences; and his first writings were concerned with problems of ethics and aesthetics. His inaugural dissertation at Rostock in the year 1910, was on the subject "The Nature of Truth in the Light of Modern Logic".

Even when he was teaching philosophy, Schlick still remained in close contact with scientific theory and research; while personal friendship was the bond between him and the physicists, Planck and Einstein, and the mathematician, Hilbert. In 1917, he wrote an introduction to the interpretation of the Theory of Relativity, under the title: "Raum und Zeit in der gegenwärtigen Physik". The following year saw the publication of his most comprehensive work: "Allgemeine Erkenntnislehre".

After a year of teaching in Kiel, Schlick was called to Vienna as Professor of the "Philosophy of Inductive Sciences", a chair which had been held before him by the physicists Ernst Mach and Ludwig Boltzmann. His

first lectures in the winter term of 1922/3 were on the philosophy of nature; and this domain was the subject of his contributions to Dessoir's "Lehrbuch der Philosophie" published in 1925[3].

Schlick's influence in Vienna was responsible for a considerable revival of philosophical activity which extended beyond the confines of the University. In addition to lectures on the philosophy of nature, on logic and epistemology, on the philosophy of life, ethics and the philosophy of history and culture, the philosophical seminars with their reports and discussions, had a great attraction for both Austrian and foreign students. Furthermore, many philosophers and distinguished representatives of special branches of science, were in touch with Schlick—as, for instance, the mathematicians and logicians, Hahn, Menger and Tarski, the sociologist, Neurath and the philosophers, Carnap, Gomperz, Kraft, Waismann and Zilsel. This circle was held together by the undogmatic and scientific way of philosophizing which demanded a foundation for every assertion—rather than by agreement in matters of opinion.

In 1929, Schlick went to America where, as visiting Professor, he lectured at the Leland Stanford University in California. And in September of the same year a Conference on the methodology of the exact sciences *met in Prague and brought the circle of scholars* known as the Wiener Kreis (Vienna Circle) into closer contact with foreign mathematicians and physicists. In conjunction with the "Society for Empirical Philosophy" organized by Dubislav and Reichenbach in Berlin, the Circle founded, in 1931, a journal

known as "Erkenntnis", in which similar tendencies found expression.

Ludwig Wittgenstein's "Tractatus Logico-Philosophicus" which first appeared in 1921 in Ostwald's "Annalen der Naturphilosophie", and then in London in 1922, contributed very considerably to the development of the Vienna Circle. Wittgenstein attributed the supposed insolubility of certain philosophical problems to their not being formulated with sufficient clarity: "Philosophy should make clear and delimit sharply the thoughts which otherwise are, as it were, opaque and blurred". But since these thoughts are expressed in language, the proper task of philosophy is the logical analysis of language.

During the period from 1926 to 1936, Schlick wrote a number of Essays which were to some extent inspired by Wittgenstein's work, and which show evidence of an extremely fruitful intellectual development. Moreover, in 1930, his "Fragen der Ethik" was published in the series known as "Schriften zur wissenschaftlichen Weltauffassung" of which Schlick and Philipp Frank were the joint editors.

Schlick was never able to carry out his plan for revising the "Allgemeine Erkenntnislehre" in the light of the new ideas and inspirations which he had acquired in the meantime. On the 22nd of June 1936, as he was mounting the stairway in the University of Vienna, to deliver the lecture which would conclude his philosophy of physics course, the fatal bullet brought his life to an end.

Amongst the writings left behind by Schlick, which included notes for lectures of an earlier date, a handwritten manuscript containing an outline of an ex-

tremely concise and significant philosophy of physics, was discovered. This was the text—of which a type-written copy also exists—on which Schlick based his lectures of the winter term of 1932/3 and which he revised, with additions, for a course in the summer term of 1936. This last version, supplemented by the editors' footnotes, comprises the main part of the present work. Since an investigation of the relations between biology and physics, although planned by Schlick, was not included in the manuscript, the editors have incorporated in the text (Sections 14 to 16) verbatim notes of his lectures of 1927 (the last which dealt with the relation of physics to biology). In the typewritten manuscript, there is also a reference to the more detailed discussion of the philosophy of nature, contributed by Schlick to Dessoir's "Lehrbuch der Philosophie"; and, with the consent of the publishers Ullstein, some parts of the latter which are important in supplementing the manuscript, are included in an appendix.

We take this opportunity of thanking Dr. Alfred Scheibel for allowing us to use his notes on Schlick's lectures of 1927.

In publishing these notes on the philosophy of nature bequeathed by Schlick, the editors' desire is to make known to all friends and adherents of scientific philosophy these last results of Schlick's thought in a domain in which he was recognized as a master by all those qualified to judge. They also desire to express thereby, a small part of their own debt of gratitude to their master.

WALTER HOLLITSCHER
JOSEF RAUSCHER

Vienna, June 1948.

CHAPTER ONE

THE TASK OF THE PHILOSOPHY OF NATURE

THE SIMPLEST way of defining the essential character of the philosophy of nature is by stating its relation to natural science. From the very beginnings of Western thought up to the age of Newton and even of Kant, no differentiation was made between the philosophy of nature and natural science; but from then on, the speculative method (that of the philosophy of nature) seemed to detach itself from the experimental procedure (that of natural science) until finally, in the middle of the 19th century, it became clear that the speculative method was a deceptive one and led into a blind alley. After that, a period followed during which philosophy was regarded with contempt by the investigators of nature, until, at the beginning of the 20th century, the term "philosophy of nature" regained its esteem and, in consequence of the unprecedented advances in natural science, a general interest in the consideration of its philosophical aspects was revived. As a result of the prevailing attitude towards philosophy in general, the task of a philosophy of nature was at first defined as 1) a synthesis of knowledge for the purpose of obtaining a complete picture of all

natural processes, and 2) an epistemological vindication of the foundations of natural science.

This is, however, an unsatisfactory definition, inasmuch as the task, or object, of natural science is the achievement of knowledge concerning all natural events and processes—in other words, it is the statement of the most general propositions, as well as an examination of the truth of the hypotheses.

The consolidation or fusion of the various branches of natural science—that is to say, the subordination of simple propositions to more and more general ones—can only occur from below, in an upward direction. For in the progress of knowledge in every field, higher and higher levels are reached, and until these levels are attained there is no possibility of achieving the synthesis which is necessary in order to obtain a complete picture. It is likewise impossible for philosophy to achieve this synthesis.—The entire task of natural science consists solely in the persistent and indefatigable examination of the correctness of its propositions which, in consequence, develop into more and more securely established hypotheses. In this way, the assumptions upon which these hypotheses are based, are simultaneously tested within the domain of natural science itself. There is, moreover, no other specifically philosophical vindication of the foundations,—such a vindication would not only be impossible, but superfluous as well—a fact which will be demonstrated in the course of the following considerations.

The task of the philosophy of nature is nevertheless concerned with the hypotheses of natural science—but in quite another sense. Natural knowledge is formulated in propositions; and likewise all the laws of nat-

ure are expressed in propositional form. But the knowledge of its meaning is a prerequisite for testing the truth of a proposition. These two concepts are inseparable, and both occur within the domain of natural science. In spite of their inseparability, however, it is possible to distinguish here between two psychological attitudes: the one concerned with testing the truth of hypotheses, and the other with the understanding of their meaning. The typically scientific methods assist in the discovery of truth while the effort of philosophy is directed to the elucidation of meaning. The task of a philosophy of nature is thus to interpret the meaning of the propositions of natural science; and therefore the philosophy of nature is not itself a science, but an activity which is directed to the consideration of the meaning of the laws of nature.

In order to establish our thesis in a complete sense, we should be obliged to define those characteristics of natural science which distinguish it from the Arts and the so-called cultural sciences. We will, however, confine ourselves to the statement that by nature we understand all that is real in so far as it is determined in space and time. All objects or processes which exist or occur in space, exist or occur likewise in time. The converse would appear not to be true; for it would be absurd to attempt to localize feelings and emotions (which are, of course, temporal) as such. They can, however, be attributed to definite individuals (namely to those who possess these feelings and emotions) and in this sense are related to spatial things. Furthermore, since all historical, cultural and linguistic objects are spatio-te ral, they are part of nature and consequently cts of natural science.

Hence, we have the universal quality and all-embracing character of natural science which prevents it from being subordinated to, or ranged alongside, any one of the Arts or cultural sciences. And hence also the unique philosophical significance of natural science: All philosophical progress in the past has arisen out of scientific knowledge and the investigation of scientific problems. It is a very grave mistake—a mistake which was made for the first time during the last hundred years—to believe that the Arts and cultural sciences are in any way equivalent to natural science, or that they are, from the standpoint of philosophy, equally productive.[1]

In addition to its universality, it is the exactitude of natural science which causes it to be, both historically and in actual fact, the most fundamental basis from which to philosophize. Only in the analysis of exact knowledge, is there any hope of achieving true insight. Only here, is there any prospect of attaining definite and final results by means of the elucidation of concepts. The vague, uncertain propositions of the inexact sciences must first be transformed into exact knowledge—that is, they must be translated into, the language of the exact sciences—before their meaning can be fully interpreted. And exact knowledge is knowledge which can be fully and clearly expressed in accordance with the tenets of logic. "Mathematics" is only a name for the method of logically exact formulation. Hence, even Kant, for instance, declared that science only contains as much knowledge as it contains mathematics. In science, more than in any other domain, the stuff or substance of knowledge is derived from an intellectual activity which enables us to arrive

at the greatest heights of abstraction. But the higher the level of abstraction attained by a science, the deeper it penetrates the essence of reality.

These are the reasons for the central position occupied by the philosophy of nature.

CHAPTER TWO

THE PICTORIAL WORLD-VIEW AND ITS LIMITS

WHILE POSTPONING all attempts at exactitude to a later stage in our investigations, we may say that a knowledge of nature, up to certain levels at least, consists in the attempt to provide a pictorial model of natural phenomena. That is to say, the attempt is made to explain how reality which can be neither grasped nor sensed as a whole, would appear if it could be surveyed in its entirety. To the question: why cannot everything be reviewed as a whole, the first primitive answer is: because it is either too large or too small. Thus, the first attempt to explain nature and to achieve a picture of the world which can be realized in imagination, consists in the construction of a model (a) of the macrocosm and (b) of the microcosm.

(A) Macrocosm

The construction of a model of this kind requires in the first place, the spatial measurement of the Universe. The earth is an almost spherical body of roughly

12,700 kilometres in diameter which, at a distance of about 150 million kilometres, rotates round the sun of which the diameter is 109 times greater than that of the earth. Alpha Centauri, one of the nearest fixed stars, is at a distance of 4.2 light years from the solar system. In order to obtain some concrete idea of these distances, we may imagine an express train which, travelling at the rate of 60 Km an hour, would require a period of some 280 years to reach the sun, and 77 million years to arrive at Alpha Centauri. Or alternatively, if we imagine our whole Universe reduced 25,-000,000,000 times in size, then the sun would appear to us as a very small globe of about 5 centimetres in diameter. On the same scale, the distance from the sun to the earth (possessing an approximate diameter of half a millimetre) would be 5 m.; from the sun to the planet Neptune, 150 m.; and from the sun to Alpha Centauri, 1300 Km—which is approximately the distance, as the crow flies, between Vienna and Stockholm, or Vienna and Istanbul.

From the standpoint of the older interpretation of natural phenomena which is still widely accepted, this kind of illustration by models must be regarded as merely a contrivance for purposes of instruction. And yet, in reality, it is very closely connected with the old idea of the explanation of natural phenomena. Indeed, the possibility of constructing models of this kind, was regarded as condition of the intelligibility of nature.

What is the philosophical meaning of this measurement of the Universe?

At a later stage of our investigations, we shall have to regard the philosophy of measurement as an important presupposition for the understanding of nat-

ure; but for the moment, we will only draw attention to essential points:

The basis of all spatial measurement consists in the application of a rigid scale, and in the measuring-off on this scale of partial lengths. In dealing with greater, or inaccessible, lengths or distances, optical instruments and light rays must be employed. And the result of the measurements can only be obtained by means of a calculation based on geometrical propositions. Thus, certain mathematical and physical hypotheses are included in all spatial measurement—a fact which makes it extremely difficult to interpret its ultimate meaning. The measurement of the earth's diameter in kilometres, for instance, would be nonsensical if the kilometre, as at first defined, were to represent a 40,000th part of the earth's circumference. For the number representing the length of the earth's diameter would in that case tell us, at most, something about the *form,* but nothing about the size, of the earth—since the length of the kilometre would again only be determined by the earth itself. As a matter of actual fact, however, the metre is not determined according to the definition introduced with the metric system, but by the standard metre in Paris[2].

The measurement of the distances of the nearer celestial bodies is obtained by the parallax method, where the diameter of the earth is taken as the base within the planetary system, while the earth's orbit is thus employed in the case of the fixed stars. Only small numbers of the fixed stars are close enough to show a perceptible parallax; but the following data concerning the spatial distribution of the stars may be accepted as authentic. The stars are not irregularly distributed but

constitute ordered groups, the so-called star clusters which consist of tens of thousands of single stars, and amongst which the globular types are by far the most interesting. Up to the present time, eighty of these beautiful spherical clusters have been observed, of which the nearest, Omega Centauri, is about 20,000 light years away from us, and the most remote, ten times as distant.—The sun belongs to a large spiral-shaped system or galaxy, known as the Milky Way, which has a maximum diameter of about 60,000, and a minimum diameter of 11,000 light years. Our galaxy contains at least 500 million stars; but it is only one of innumerable similar systems which are revealed in the telescope as the so-called spiral nebulae. The majority of these do not consist of nebular or diffuse matter, but of thousands of millions of suns. The nearest of these systems or galaxies—that of the nebula in Andromeda—is at a distance of 900,000 light years from our solar system; and our telescopes have so far revealed about 2 million of these nebulae. But, without doubt, many more exist.

The estimate of distances which cannot by measured by a determination of parallaxes, is obtained by Shapley's Cepheid method. The Cepheids are variable stars which show periodic fluctuations in brightness; and (according to Plummer and Shapley), they are pulsating gaseous spheres, the characteristics of which can be easily deduced from physical laws. The star, Delta Cephei, from which the rest of the species derive their name, is a very large star—about 700 times as bright as our sun,—with a period of 5½ days. The distance of these stars—and hence the distance of the constellations in which Cepheids are to be found—can

be calculated both from their absolute brightness which is known, and from their apparent brightness in the sky. The apparent size of these stars furnishes a basis for calculating the distances of the remotest galactic systems. The important thing is to ascertain how many physical hypotheses are included in these measurements of distance, and how far they must be taken into consideration in the interpretation of such measurements.

We would point out the following considerations with respect to the visualization form and size of the *Cosmos:*

After Giordano Bruno, the Universe was regarded as infinite in extent. But the new astronomy believes it to be finite. If, in an infinite space there were to exist an infinite number of celestial bodies averaging our sun in size, and uniformly distributed throughout space, the whole heavens would appear as bright as the sun's disk. In reality however, it is many million times darker. Furthermore, the hypothesis of the non-finite mass of the totality of all stars, was not compatible with Newton's law of gravitation. And so hypotheses concerning the infinity of gallactic systems, for example even those according to which the Cosmos consists of a hierarchy of infinitely numerous Milky Way systems one superior to the other, are disproved. The theory that the world represents a finite island in infinite space, was likewise confronted with certain difficulties to which we shall return later. On the other hand, the consequences of Einstein's General Relativity Theory, whereby the space of the Universe is finite but unbounded[3], are both logically satisfying and in accordance with the facts. Here there is no longer any visual-

ization model. We have arrived at a boundary which the older method of investigation of nature was powerless to cross.

The Temporal Evolution of the Universe

There was a time when the problem of the origin of the solar system occupied the foreground of general interest. The theories of Laplace and Kant which sought to render the present structure of the planetary system intelligible by regarding it as a natural stage in the evolution from what had originally been a more or less globular, diffuse, nebular mass distributed in space, are well-known. To-day, we know that this development, suggested by Laplace—or another of similar kind—can only culminate in the formation of a multiple star from a single one (actually, nearly a third of all the visible stars are double stars). We also know that it is highly probable that our solar system owes its origin to a chance collision or, more likely still, to the close proximity, of two stars[4]. Because of the small probability of such proximity, it is unlikely that more than a very few fixed stars have planetary systems. As a matter of principle, it should be realized and noted that in scientific cosmology, the present more complex and ordered state of the world, can never be derived from simpler and more chaotic conditions. The degree of differentiation, order and multiplicity remains the same throughout all transformations. As a result of this observation, the philosophical significance of the theories of the evolution of the world is reduced to a minimum.[5]

To-day, the new knowledge concerning the evolution of the stars which has been gained by the combined

efforts of astronomy and atomic physics, is of great importance; and as a result, the temporal conditions existing in the Universe can only be considered in relation to the material (see Stars and Atoms, by Arthur Stanley Eddington. Cambridge University Press (England) 1927). Even, in his time, Auguste Comte expressed the opinion that man would never arrive at a knowledge of the kind of matter, or substance of which the stars consist. This was an extremely unphilosophical utterance, in which the fundamental role of spatial distance as a condition of knowledge was overestimated. It is due to an error in reasoning such as cannot occur if we adopt the standpoint represented in this chapter concerning the model-like character of knowing.

The method whereby we learn most about the structure of matter is just as applicable to celestial as it is to terrestrial objects—namely that of spectral analysis. Not only are the various chemical substances differentiated by the spectrum of the light which they emit when in a state of incandescence, but we owe to spectral analysis our entire knowledge of the interiors of atoms. Observations made in the laboratory and in inter-stellar space—where conditions are completely different from those prevailing on the earth—supplement one another. And if at one time it appeared as though in the stars and nebulae substances occurred which are unknown on the earth, it is now an undoubted fact that matter throughout the whole Universe is built up of the same components—namely, of particles of positive and negative electricity and quanta of radiation (protons, electrons, photons) which combine in a great variety of ways to produce the atoms of the

so-called chemical elements[6].

By combining with actual observations all that physics tells us of the nature of physical structures like the stars, we come to the conclusion that the stars are undergoing a process of evolution in which while their volume is reduced by radiation and their mass by contraction, their density and temperature increase wherever there is a fairly constant total brightness or luminosity. Thus according to Eddington, a large star of the type of Algol will, within a period of 5 billion years become a star of the yellow type of our sun which in its turn, within a period of 500 billion years, will become a red star of the type of Kruger 60.

But the latest observations of the remotest spiral nebulae—made for the most part from the Mount Wilson Observatory in California—are responsible for temporal estimates of quite another order; and also for the most astonishing conclusions regarding the destiny of the Universe. These observations show that the spiral nebulae are receding from us with great velocities; and according to Hubble's law, this velocity of recession is proportional to the distance. At a distance of 40 mega-parsecs[7], for instance, it amounts to nearly 25,000 Km per second. Such measurements are carried out from observations on the displacement of the spectral lines, in accordance with Doppler's law[8].

Thus, the Universe is not in a state of equilibrium, but according to the equations of Einstein, Friedmann and Lemaitre, is expanding rapidly—so rapidly that in a period of 1300 million years, all the distances in it will be doubled. If extrapolation in accordance with Hubble's law were permitted, the velocity of the spiral nebulae would, in some 2000 million light years, have

attained that of light itself (300,000 Km per second (Transl:)); and 200,000 million years ago, the total mass of the Universe would have been concentrated in one cubic millimetre. The first of these consequences, which is incompatible with the Theory of Relativity, can only be avoided by declaring such an extrapolation to be physically absurd—inasmuch as all statements concerning space and time, change their meaning as soon as certain dimensions are exceeded. (The expansion of an inter-stellar space with a similar constitution could not exceed a couple of million light years). The second of these consequences is disproved if the expansion is assumed to hold only for the total system of Milky Way galaxies and not for each one of them separately—a presumption which could be supported by the Friedmann-Lemaitre equations. In that case, the expansion would perhaps have only just begun when the process of stellar evolution in our Milky Way was already at a very advanced stage. But empirical discoveries resulting from the investigation of minerals containing uranium and of meteorites, suggest an age not exceeding 2 thousand million years for the earth and neighbouring worlds—in which case, it is possible that the yellow and red stars do not represent different stages of evolution.

Although pictorial analogies with the expanding Universe can be made by a comparison with soap bubbles and the like, it is impossible to construct visualizable *models* of this phenomenon.

(B) Microcosm

The facts of modern atomic theory are so well known that any further detailed description of them

is unnecessary. The concept of the atom as conceived by Leucippus and Democritus in antiquity, was introduced by Dalton in the year 1808, as a scientific hypothesis to explain certain chemical facts. And later it was successfully applied in the explanation of the *physical* properties of substances: in the kinetic theory of matter and particularly of gases. According to the latter theory, molecules and atoms were regarded for the purposes of calculation, as being perfectly elastic spheres. They moved freely in gases with velocities of several hundreds of metres per second, until they collided, either with the side of the receptacle or with a neighbouring molecule, and recoiled. The average energy (kinetic energy) of the particle is proportional to the temperature; hence, heat is explained as a form of motion. The number of atoms per cubic centimetre of gas at zero temperature and pressure, is 27.10^{18}; and the number of atoms in a cubic centimetre of water is 10^{22}. These figures are considerably higher than those representing the number of the stars which we learn from astronomy. While the kinetic theory of matter is adequate to explain all general mechanical and thermic properties, the atom as an electro-dynamic system, must be introduced in order to explain both optical and electrical phenomena. And this is achieved by means of the Rutherford-Bohr model of the atom in which electrons—the number of which ranges from 1 to 92—rotate round a central, positively-charged nucleus containing both protons and electrons. The important thing about this model is that the electrons can only move in certain, discrete tracks; and that the atom only emits rays (photons) when an electron jumps from a larger into a smaller track, and only absorbs

rays when the jump takes place in the reverse direction. For our purpose, it is important to realize that this model only gives us a visualization of the spatio-temporal, but not of the electro-dynamic relations. The attempts to construct a pictorial model of electrical and magnetic processes which were persisted in from the time of Faraday and Maxwell to that of Lord Kelvin, have long since been finally abandoned. We have already arrived at a limit to the pictorial world-picture, of which the inadequacy is even more clearly brought home to us by modern quantum theory which shows that even in respect of spatio-temporal conditions, the model must fail. There are three reasons why a pictorial model of the atom must be inadequate:

1) The smallest elements (electrons, for instance) must be represented as visual or tactual particles. And as a consequence of their definition, this is impossible.

2) The essential nature of the model, represented by its electro-dynamic properties, can neither be perceived nor imagined.

3) The spatio-temporal structure of the model which seemed to represent most clearly an immediate image of nature, can no longer, in view of modern physical theory, make such claims.

In order to arrive at a clear conception of the value and limits of pictorial (model-like) knowledge, we must first attempt to discover an exact foundation for the explanation of natural phenomena.

CHAPTER THREE

DESCRIPTION AND EXPLANATION

THE FIRST step towards a knowledge of nature consists in the description of nature which is equivalent to the establishment of the facts. And this, in turn, consists in stating, by means of words or symbols, how the facts described are composed of elements, each of which is denoted by the customary symbol (name). For this purpose, certain primitive acts of recognition are always necessary, so that each component can be identified as belonging to a definite class and assigned to a corresponding symbol[9].

The next step towards a knowledge of nature—explanation—is characterized by the fact that a symbol (concept) which is employed in the description of nature is replaced by a combination of symbols which have already been used in another context. In point of fact, progress in knowledge consists in the discovery that a substitution of this kind is possible. Thus it is a chemical discovery when, instead of the word "water", we can say: "combination of H and O in proportionate weights of 1:8"; and it is a physical explanation when, instead of speaking of the heat of a body, we can speak of the energy of motion of its smallest particles. And so on. The advantage of this new kind of description

lies in the fact that, with its assistance, the ways of behaviour of the things thus designated, can be predicted —inasmuch as this behaviour can be deduced from the behaviour already known, of those things which are denoted by the concepts used in the explanation. If, for example, heat be explained as a form of motion of the smallest particles, we can, as a result, attribute all phenomena of heat to the properties of the invisible motion of a host of the smallest particles, and thereby predict phenomena of heat which had previously been unknown to us. It is obvious that in the progress of knowledge, the number of concepts necessary for a description of nature, will become increasingly reduced; so that what is denoted by the term "world-picture" will become more and more unified. The world will become a "*Uni*-verse". It is evident from their attempts to reduce the multiplicity of the Universe to a single principle, that even the Greek philosophers of antiquity were conscious in a dim way, of the ultimate goal of knowledge. This idea was at the root of Thales' theory that water is the primal substance of the world; while for Anaximenes and Heraclitus, air and fire respectively, filled this role.

Explanation means the discovery of like in unlike —of identity in difference. And inasmuch as explanation reduces different species of natural phenomena to the same domain, these different species are included as special cases in the latter. Hence we may say, that explanation is the inclusion of the special in the general. Thus, heat and sound, for example, are both explained in so far as they are regarded as special cases of the motion of the smallest particles.

In the first stages of scientific thought, the discovery

of the similar in the dissimilar was interpreted as the discovery of a constant, an invariant—something which remains identical with itself and which, while it is the basis of all variety and change, has no part in them. This constant was called *substance,* and was supposed to occur in a multitude of apparent forms and to be subjected to a variety of processes without its essential nature being altered thereby. This primitive concept of substance, the logical deficiencies of which will become evident later, was even then inadequate. For how this substance came to be differentiated and to undergo such transformations, remained unexplained. Change itself must be rendered intelligible by the discovery in it of the unchanging, or invariable—and for this purpose, the concept of law is necessary.

"General descriptions" constitute a preliminary stage in the procedure (e.g. "a stone which is thrown, falls to the ground"). These general descriptions may even be termed laws; but they still do not constitute an *explanation* of the processes described. Such an explanation can only be achieved when a number of laws of the kind are united in a single law, and when one is recognized as a special case of the other. In that case, *one and the same formula* will describe a number, or indeed, an arbitrary number, of processes. This is the essence of Meyerson's interpretation of the rôle which "identity" plays in the explanation of nature. An explantion is perfect only when this formula is specified with the help of the mathematical concept of "function". For it is only with the help of a formula of this kind that it is possible to obtain a description which is complete in all details.

Galileo was the original creator of this kind of

exact natural knowledge. We will first attempt to get a clear idea of the essential character of the natural law which was enunciated by him as the law of falling bodies. We imagine a freely falling body, whose velocity v is measured at many points on its path. We divide these velocities by the time t which the body has taken in order to reach the corresponding points on its path. The quotient will show the same number each time (called g), although the numerator and denominator are constantly changing during the fall. Thus the quotient represents the constant element in the change, or the invariable in the variable. Generally speaking, the formulation of a law concerning any natural process consists in stating the *particular combination* (function) of those variable magnitudes or quantities describing the process, *which remains constant during the whole process.* Galileo "explains" *why* the falling body had traversed a certain distance in a certain time. Newton again, explains Galileo's law, inasmuch as he shows it to be a special case of the law of gravitation. And Einstein explains the law of gravitation inasmuch as he reduces it to a general principle of inertia.

The explanation of nature means a description of nature by means of laws. The function of laws (the meaning of laws) is to *de*-scribe and not to *pre*-scribe. They relate what actually occurs, and not what ought to occur. And when necessity is ascribed to the laws of nature, this means that they are universally valid, and not that they exert force. The laws of a country or State, are forms of compulsion for the citizens of that State. But to speak of compulsion, or force, in the case of the laws of nature, is absurd. One is misled into doing so, because, of the ambiguity of the word "law"

—and this, in turn, is due to the half-conscious use of a psychological model.

Psychological models of this kind, in which natural processes are conceived of in accordance with the pattern of psychic events, constitute the basis of the mythical explanation of the world, and of the animistic conception of nature. They are also responsible for a number of metaphysical systems, like that of Schopenhauer, for whom natural processes represented the manifestations of a hidden Will. Bergson's life force (élan vital) plays a similar rôle and likewise represents a primitive psychological model. It is characteristic of both these philosophers that they set up, in opposition to the scientific explanation of nature by means of laws, a philosophical knowledge which they claimed was deeper. This deeper philosophical knowledge does not consist in description, but in a real coalescence with the subject-matter of which knowledge is sought. Only thus, in their opinion, can true understanding be attained. But these philosophers do not realize that description by means of laws achieves all that can possibly be demanded of knowledge; and that psychologically intuitive models only *apparently* advance the understanding of nature—in reality they obstruct it more than does the use of a mechanical model. The word "force" also—the meaning of which we shall analyse later—owes its introduction into science, to a psychological model[10].

CHAPTER FOUR

THE CONSTRUCTION OF THEORIES

THEORETICAL SCIENCE, as is obvious from its name, consists of theories—that is, of systems of propositions. Propositions constitute a system when they are related to one another through being concerned with the same objects; or even when they can be deduced from one another. The process of formulating a law of nature is, fundamentally, always the same. It consists, in the first place, of recording the observations of a natural process in a table which always contains the relevant measured values of those variable magnitudes which characterize the process. The next step is to discover a function which will represent in a single formula the distribution of values in this table. This formula is then considered to be the law describing the process as long as all new observations are in agreement with it. Inasmuch as the formula always contains more than what is actually observed, and also because it must hold for all processes of a similar kind, the formulation of any law involves a generalization, or a so-called induction. There is no such thing as a logically valid deduction going from the particular to the general: the

latter can only be conjectured, but never logically inferred. Thus, the universal validity, or truth, of laws must always remain hypothetical. All laws of nature have the character of hypotheses: their truth is never absolutely certain. Hence, natural science consists of a combination of brilliant guesses and exact measurements.

The process of measurement assumed here, raises questions which must be discussed at a later stage.

In the same way as a special law is the result of a series of single observations, a general law is the consequence of the inductive combination of several individual laws, until finally a relatively small number of general propositions which include the totality of natural laws is obtained. Thus to-day, for instance, all chemical laws can, in principle, be reduced to physical laws; and the dividing line between the different domains of physics which used to be externally related to one another (mechanics, acoustics, optics, theory of heat etc.) has long since completely disappeared. At the present time, only mechanics and electro-dynamics are left; and these are in nowise independent of each other, but interpenetrate everywhere. Whether biology will continue to remain a special province, or whether it also will become incorporated in the domain of physics, is a question that will be discussed in due course[11].

In order to obtain a concrete description of nature (i.e. of nature as it really is), it is not sufficient to formulate laws: the abstract laws must, as it were, be given content. And in addition to these abstract laws, the constellation of reality (at the time of consideration), to which the formulae can be applied, must be stated. Such constellations are called by physicists boun-

dary or initial conditions; and mathematically, they are expressed by the introduction of constants.

Here, we are considering the system of laws in itself, independently of all applications—that is to say, we are only studying general, and not particular, propositions. We can thus select out of this system, a group of the most general propositions from which all the others are derivable. This derivation is a purely logical deduction which can be undertaken without knowledge of the meaning of the symbols which occur in the laws. Hence, we will disregard, not only all application to individual cases, but also the meaning of all words and symbols—until the system is reduced to a purely formal structure, or empty framework which does not consist of actual propositions, but only of their forms (in logic, these are known as propositional functions). A system of this kind, which does not represent nature in actuality, but *all the possibilities in nature,* or in other words, its most general form—is known as a hypothetico-deductive system (Pieri). The propositions forming a group at the apex of this system, are called axioms; and the choice as to which propositions shall be taken as axioms is, to a certain extent, arbitrary. We may regard any proposition as an axiom, so long as we fulfil one condition, which is that all the other propositions in the system be derivable from the chosen group of axioms. Thus, the quality of being an axiom is not in any sense a natural, intrinsic attribute or characteristic of a law; the only reason for choosing certain propositions as axioms, are those of their expediency or convenience. In the propositions derived from these axioms, further symbols, other than those used in the axioms, are intro-

duced *by definition.* A definition consists of the introduction of new symbols, or signs, for the purpose of abbreviation. The choice as to which of these signs shall be regarded as fundamental symbols and which as derived from the latter by definition, is likewise arbitrary.

Examples:

$E = \frac{1}{2}mv^2$	$M = mv$
Definition of Energy	*Definition of Momentum*

But instead of mass and velocity, we can also write:

$$\frac{\text{Energy}}{\text{Momentum}} \quad : \quad v = \frac{2E}{M}$$

Thus, it is immaterial which magnitudes or quantities occur in the axioms.

Hence, the structure of a theory consists of: 1) axioms; 2) derived propositions and 3) definitions. In the symbolic representation of natural science, whether by means of words or of mathematical symbols, the three structural elements cannot be outwardly distinguished from one another.

The symbolic representation of a theory consists of sentences which in their turn are constituted of certain series of spoken or written signs; the theory itself consists primarily of "propositions". The question as to whether a sentence represents a true proposition or only a definition for example,—depends on the interpretations which explain it and give it its meaning. These do not form part of the symbolic representation itself, but are added to it—that is, they are added to a hypothetico-deductive system—from outside as it were,

for example, in the form of ostensive definitions. They constitute the rules of the application of the sentences and are conclusive for the philosophical interpretation of the latter. It is, after all necessary to refer to a reality which is described by the system of signs or symbols since, at some time or another, we must break out from this system[12]. Only those sentences which by virtue of their interpretation, represent genuine propositions, can communicate something about nature; the others are merely internal rules for signs and consequently are definitions. We shall discuss later the confusion of true laws of nature with sentences which merely fulfill the function of definitions[13].

CHAPTER FIVE

THEORIES AND PICTORIAL MODELS

THE CONNECTION between theory and reality was formerly always conceived of as though the symbols occurring in the laws of nature represented simple magnitudes, or quantities, which could either be immediately perceived, or could at least be regarded as being of the same nature as such magnitudes or quantities (e.g. a length of 1/100mm). Thus, in Newtonian mechanics, the fundamental concepts represented by lines in space, time, and mass, were three terms of which the meaning seemed to be derived immediately from sensory imagery. All three are combined in the concept of motion, which is equivalent to temporal change in the spatial position of a mass. Motion is that process in which the basic requirement for knowledge appears to be fulfilled in a pictorial manner—namely, as the perception of the constant element in change. That which is moved—the mass—fills the rôle of substance, and remains unchanged in sense-perception. And yet, something does change—namely, the position. The whole process seems to be perfectly clear and visually conceivable; and this is the only reason for the predilection for mechanical explanations, and for the desire of earlier physicists to reduce their science to

mechanics. Hence also, the peculiar extension in meaning of the word "mechanism".

In the mechanical explanation of nature, it was necessary to assume the existence of invisible motions, in order that observed processes might be reduced to them; and this was successful in both acoustics and the kinetic theory of heat. *But in order to* explain electro-magnetic phenomena and radiation, the hypothesis of the so-called aether of space, to which at first the same properties were ascribed as to the substances accessible to every-day perception, had to be introduced. Thus the aether was conceived of, alternatively, as a gas, fluid or solid body. It was then discovered, however, that in this way, certain self-contradictory properties would have to be attributed to it; and hence, this very crude type of knowledge based on models, was reduced to an absurdity. Actually, the assumption that the aether must possess the same properties as substances that can be weighed, the qualities of which were to be rendered intelligible with its help, were unjustified (Poincaré). The processes which are supposed to take place in the non-perceptible microcosm, need only fulfil the condition that in virtue of their interaction they give rise to those processes which can actually be observed in the domain of the perceptible. We call the laws governing these invisible processes, small-scale, or micro-laws; and those governing perceptible processes, large-scale, or macro-laws. This distinction must occur in every theory; for in every theory, the observed behaviour of things is ascribed to small-scale laws to which the most general hypotheses of natural science are also referred.

Micro-laws and macro-laws could only be identical

by a very improbable chance. There is no a priori justification for such an assumption which is essential for the most primitive type of knowledge based on models.

The atomic theories of Democritus, Boscovitsch and Heinrich Hertz, as well as the vortex ring theory of the atom, are all examples of knowledge based on models (See M. Schlick: "Naturphilosophie" in Dessoir's "Lehrbuch de Philosophie")[14].

Poincaré proved that for every mechanical model discovered, there are always others which can achieve the same results. It is generally true to say that micro-processes can never be unequivocally deduced from observed large-scale processes—a large number of possibilities always exists. In an advanced stage of scientific development, such as that of physics during the first quarter of the present century, the claim to regard micro-processes as analogous to large-scale processes, was, in principle, abandoned. But so long as one retains the assumption, if only in part, that micro-processes are to be construed in perceptual terms, the method of models has not been entirely discarded. Thus, in Bohr's model of the atom, for example, it is still assumed that there is some sense in speaking of an arbitrary physical event with its spatio-temporal magnitudes arbitrarily enlarged or diminished. It is only in the most recent phase of the development of physics that the extension to the realm of the invisibly small, of spatio-temporal conditions prevailing in the regions of the directly measurable, is no longer regarded as permissible. Accordingly, micro-processes conceived in a visualizable manner and the method of representation by models, have been abandoned.

CHAPTER SIX

ON THE MEANING OF SPATIAL DETERMINATION

HITHERTO, WE have regarded a model as a pictorial, imaginable structure. To imagine "pictorially" means to depict in imagination the perceptions which one would have if one were to observe or handle the structure directly. And for this to be possible, the structure must be neither too large nor too small; and in any case must be a spatial structure. Thus, in order to evaluate knowledge by models, one must understand the nature of the spatial. Furthermore, since we have defined nature as that which exists in space, the analysis of the concept of space must, in any case, occupy a central place in the philosophy of nature.

We must first of all distinguish between the one *objective, physical* space and the *spaces of perception* of which there are as many as we possess types of sense-perception. The most important of the latter are those of sight—or vision—and touch. These two are qualitatively entirely different and cannot be compared with each other. Nevertheless, they have in common certain uniform, formal and quantitative characteristics of order; and it is these which enable us to define

physical space in a manner that will be described later in greater detail.

While the individual visual and tactual perceptions are subjective (that is to say, the propositions about them depend on the observer), they still exhibit an order which may be called "objective" because it is described by propositions that are independent of the modality of sense-perceptions and, moreover, can be verified by any number of observers[15]. Physical space is described by a system of such propositions. Thus, this space itself is not pictorially conceivable,—only certain ordered sequences of perceptions, whose order represents exactly the physico-spatial properties of the assumed structure, are imaginable. In our attitude to this problem, we do not inquire as to the "essence" or "intrinsic nature" of space (it is significant that this word does not occur in every-day language), but instead, we ask what it means when we formulate propositions concerning certain spatial properties of natural objects, or natural processes.

In order to describe spatial conditions, we require in the first place, the concept of the point, of which the perceptual foundations consist in the occurrence of certain special positions (singularities) in the visual and tactual fields, which we are accustomed to describe by saying that they are not extended—in other words, that no parts of them are perceptible.

It is characteristic of these singularities that they can be altered considerably by the slightest movements of the sense-organs (they can, for example, be caused to disappear). And this is why we ascribe the dimension 0 to a point. A line, on the other hand, has a direction; whereby the sense-impression in the case of very small

displacements, remains unaltered (a line is one-dimensional). Now what do we mean when we assign to a line (that is, to the distance between two extreme points) a certain definite length? We may on no account say that we are stating thereby the amount of empty space—that is, the amount of Nothing—which lies between these two points (compare Descartes' arguments). The only way of establishing the meaning of a specification of length is to consider how such specification is instituted. Generally speaking, there is no other way of ascertaining the meaning of a proposition than by considering how its truth is established. The only valid method to apply in natural knowledge is that of observation and experiment—that is, of certain definite operations. And this is true of the measurement of lengths. The comparison of the lengths of two lines is carried out in principle, as follows: two points on a standard body used for comparison, are chosen (points of a compass, or marks on a measuring-rule) and are made to coincide with the two end-points of one line; they are then transported to the second line, and the process is repeated. It is thus a question of establishing the coincidence, or non-coincidence, of pairs of points. The sensory basis of a coincidence of this kind, consists in peculiar singularities in the fields of perception which possess the character of objectivity in the sense we have described.

It is extremely important to note that a *completely* strict difference between true coincidence and very close proximity can*not* be defined by this method—whereas in mathematics, an essential topological difference (essential distinction) between the two concepts, is made.

In applying the method of measurement that we have described, it is assumed that the measuring-rod does not change its length during the process of transportation; and that we can thus be certain of a length remaining constant in different localities. But this assumption could only be proved by the application of another, *new* scale, when the same procedure would start all over again. The comparison thus leads us into an infinite regress, or logically vicious circle, which we can only overcome by realizing that the equality of two lines is nothing absolute,—that it is not something given in the world, and complete—but that the concept is instituted only by means of a *definitory decision.*

This decision cannot be made on a logical basis, but only from a practical standpoint. It involves the concept of a "rigid body". If the body be characterized by the fact that two points marked out on it, coincide with two points marked out on a second body and that these coincidences remain constant at all points and at all times, it is said that the one body *is rigid with reference to the other.* Experience shows that a whole class of bodies is distinguished by the characteristic that each one of them is rigid with reference to every other of the class. We designate all these bodies as being "practically rigid". A closer examination shows us that according to the definition, no body is completely rigid. And this prevents us from using, unreservedly, any real body as the normal measuring scale in a comparison of lengths; and causes us to append conditions (corrections) whereby, for instance, we state: "If the standard measure is subjected to a certain temperature, a definite fraction must be subtracted from its length". Or: "If it be subjected to such and such a force, then

such and such a fraction must be added to its length". By means of such rules, the real scale becomes compared, as it were, with an ideal scale which is regarded as being perfectly rigid.

If a concept be defined with reference to a real, existent frame or body (such as the earth's meridian, the standard metre in Paris etc.), we then speak of a *concrete definition*. But if it be referred to a natural law or general uniformity, then we call it a convention (Poincaré). (Convention in the narrower sense, since in the wider sense of "agreement", every definition is a convention).

Since we assume the laws of nature to be invariable (the meaning of this assumption will not be examined for the moment), the convention, as contrasted with the concrete definition, has the advantage that the concept defined by it, can be reconstructed at any time (compare the wave-length of light)[10].

We have so far only mentioned the concept of equality and of greater and less, in respect of lengths. Further operations are, however, necessary in order to accomplish the *measurement* of lengths—or the (unequivocal) characterization of definite segments by means of definite numbers. For this purpose, we require a rigid scale on which many marks are drawn. These marks are indicated by numbers, but they can, in principle, be arranged and designated arbitrarily. This rule or scale is then placed on the line which is to be measured in such a way that the initial point of the latter coincides with a definite point on its scale. Then, the end-point of the line coincides with another point of the scale, and the number ascribed to this is called the length of the line. The first definite or fixed point on

the scale is denoted as 0. The scale is so adjusted that the intervals corresponding to equal differences between the numbers, are equal to one another (according to the previous definition); that is to say, that the intervals between the numbers 0 and 1, 1 and 2, 2 and 3, and so on are made equal in extent. In this way, the addition of distances requires only a very simple sum, or theorem of addition. If, by the "sum of two lines", the length of that line which results from placing the two together, is to be understood, then this length will simply be equal to the arithmetic sum of the units of measurement, or scalar numbers, of the two lines. Finally, the lines having a length equal to 1, remain to be determined by a concrete definition (in connection with the size of the terrestrial globe), or by a convention (with the help of the wave-length of certain kinds of light). There are thus five conditions necessary in order to determine length. It must be stated:

1) when two lines are to be considered as equal
2) what is to be understood by larger, smaller
3) where the number 0 is to be placed
4) where the number 1 is to be placed
5) how the remaining numbers are to be ordered

The first two of these conditions are known as topological, the last three as metrical, conditions[17].

The introduction of optical appliances in measurement does not establish anything new in principle. These are concerned with the observation of singularities in the visual field only; and assumptions must be made concerning the behaviour of light rays (rectilinear propagation). It is nevertheless worthy of note that the optical method can be so conveniently applied that none of the conventions on which measurement

according to a rigid scale is based, need be altered. The most important result is that every metric determination of spatial conditions depends on *comparison,* and is in consequence relative. All measuring operations consist of comparisons between rigid bodies accomplished by observations of coincidences. All spatial propositions are referred solely to the behaviour of bodies—never to "space". In agreement with Poincaré, we are convinced of the relativity of all spatial propositions, on the grounds that it would make no perceptible difference to the world if we were to assume that overnight the measurements of all objects in it had been changed in the same proportion. For, inasmuch as according to this hypothesis, all scales of comparison —including our own bodies with their sensory apparatus—would be changed in the same way, there would be no possibility of confirming the supposed change by any measurements whatsoever—not even by the accuracy of the eye. So long as the coincidences are maintained, the world might be subjected to any number of conceivable deformations and nothing would be changed.

Helmholtz had already realized this fact when he pointed out that beings living in a world such as would be engendered by the reflection of our world in a distorted mirror, could never by any means, become aware of the distortion, so long as they were unable to pass from their world into ours and so compare the two[18]. To speak of the deformation of the world is only significant if something were to exist which did not participate in it, and through which the change could be confirmed—obviously by the observation of coincidences. A distortion in which all coincidences

are maintained (where no new ones are created, and where none disappear) does not represent a change in the world, but only the introduction of a new way of speaking—a new terminology—such as, for example, the substitution of any type of Gaussian co-ordinates for a Cartesian system of reference. Where all coincidences are maintained, the only meaning of a distortion would be the assumption of a change in the lengths of rigid bodies, and hence in that of the measuring scales. But this would involve a contradiction of our definition of lengths, according to which a length is determined solely by coincidences.

We have hitherto only been able to speak of points, lines and spatial figures in a physical sense (which means that a straight line for example, represents a physically distinct object). By a line, we mean a continuous series of material points on a body (edge). The introduction of an arbitrary, ideal system of reference, can only be effected if we imagine to ourselves systems of lines (bundles of surfaces) distinguished physically, and agree that these are to serve as coordinates. I can describe nature with the aid of any arbitrary system of reference—or, as one is accustomed to say—with the help of arbitrary geometries.

If it were possible to formulate the laws of nature in such a way that they contained exclusively those propositions concerned with coincidences, which are true for *any* systems of reference whatsoever, they would then contain a minimum of arbitrary methods of description and would, in consequence, reproduce nature, so to speak, in the most faithful manner possible.

Newton was aware that geometry is a part of physics when he declared it to be "that part of general me-

chanics which both establishes and determines the art of measurement". And Einstein expressed the same view when he declared geometry to be the "theory of all the possible arrangements or groupings of rigid bodies". (Einstein: Geometrie und Erfahrung, Berlin 1921). We must distinguish between geometry as the theory of the positional relations of rigid bodies from the "pure" or "mathematical" geometry which may be described as a hypothetico-deductive system in the sense which we have already explained. The mathematical geometry of Euclid originated in the following manner: experience showed that from the observations of certain positions and magnitudes, together with certain general assumptions, certain other (new!) observations could be predicted; and that this procedure rendered the actual process of measurement unnecessary. It was discovered that in order to calculate the volume of a cube, for instance, only one side need be measured; and also that the measurement of two angles of a triangle, gave the third angle. The corroboration in these cases of the predicted results, confirmed the correctness of the general assumptions. Now, if these general assumptions, together with all the propositions which can be derived from them, be considered merely with respect to mutual interrelations, and if the meaning of the words or symbols occurring in them be completely ignored, we get a "pure" geometry, or a purely formal system of axioms and theorems, devoid of content, and therefore not genuine propositions, but so-called propositional functions. Once this idea is grasped, the mathematician can think out any number of such systems, and investigate their internal relations. And the investigator of nature can test their

applicability—that is, he can discover whether there exist any kind of natural objects which can be introduced to fill out the empty propositional forms of the axioms so that true propositions ensue. If such be discovered, then the theorems deduced from these axioms, are obviously also true.

Poincaré thought that we should always be desirous of obtaining the simplest possible geometrical theorems and would consequently prefer Euclidean geometry. In reality, however, it is much more important, or convenient, to choose the conventions in such a way that in their application to nature—that is to say, in the transition from pure to physical geometry—the simplest possible system of physics results (if Poincaré had lived to experience the latest developments in physics, he would have welcomed the application of non-Euclidean geometry to the description of nature.

The transition from pure to physical geometry corresponds to the transition from the *theory* to the *application* of language. Pure geometry is the grammar of physical geometry.

In the description of nature, one can use the term "straight line" for instance, for those structures which obey the axioms governing the Euclidean straight line; in which case the sum of the three angles of the triangle formed of three such structures, is equal by definition to 180°. But since 1919, we know that this condition is not always fulfilled in the case of the light rays of astronomy. Nevertheless, it is still possible to stipulate that by "straight lines" one is to understand such structures as light rays, taut string and so on. And that this condition is not always sufficient in the case of the light rays of astronomy. Nevertheless, it is still

possible to state that by "straight lines", such structures as light rays, taut string and so on, are intended. And this means that we prefer to describe nature with the help of a non-Euclidean geometry. Both possibilities exist, and the opinion of some philosophers that only the first corresponds to the "true nature" of a straight line, is devoid of meaning. We must, in any case, specify by means of definitions what we are to understand by a "straight line". And such specifications or decisions are, in principle, quite arbitrary.

The a priori view that the fundamental concepts of geometry—like that of straight lines—are indefinable, and that their content and universality are both independent of physical experience and are given in "pure perception", does not withstand a critical examination. On the contrary, these fundamental concepts in their original form, denote only special kinds of physical structures.

CHAPTER SEVEN

THE FOUR-DIMENSIONAL WORLD

AS AGAINST our preceding argument to the effect that is is meaningless to speak of a spatial deformation in which all objects participate, it could be objected that although the distortion may not result in perceptible changes in magnitude, it may nevertheless give rise to changes in physical behaviour, provided that the latter are not excluded by special assumptions concerning the values of the constants of nature either before or after the deformation. But if we ask how these constants are to be discovered, we find that this is achieved by establishing a connection between various coincidences—a connection which involves the *simultaneous occurrence* of the coincidences. (The pointer of a galvanometer must, for instance, indicate a definite number, while the mercury column of a thermometer arrives simultaneously at a definite mark on the scale). Thus, we need only add that the relations of simultaneity between neighbouring coincidences are not to be affected by the deformation, and we can, then, be quite certain that observation can yield no other constants or natural laws, and that the supposed change is not actual but only a change in the way of speaking. It follows, therefore, that the description of nature is solely

a question of spatio-temporal coincidences. The meaning and scope of this proposition is most clearly demonstrated—according to Minkowski's method—by a graphical representation in which time is introduced as the fourth co-ordinate in addition to the other three spatial co-ordinates.

The world thus described is a four-dimensional continuum traversed by world-lines, each of which is the image of the motion of a point (material point, or packet of energy). Since the world-lines represent motions, a deformation of the four-dimensional model denotes a change in the states of motion, e.g. some kind of curved and irregular motion of a particle could succeed a state of rest or uniform rectilinear motion of the same particle. Now since—as we have seen— a deformation never describes a genuine change, but only a change in the way of speaking, it follows that whether we ascribe a position of rest or some kind of motion to a particle, is also only a change in the way of speaking. Actually, the type of motion of a particle depends solely on the choice of a system of reference.

The description in terms of world-lines is limited to objects which satisfy the condition of "genetic-identity"[19] or, in other words, to objects of which it can be said significantly that they have remained "the same" during a finite period of time. In this model, the coincidences are represented either by sections or by tangents of world-lines. A model of this type can be distorted in a completely arbitrary manner and, provided that the topological relations of the world-lines are not deranged, it is an equally adequate representation of reality.

The world-lines describe the motion of particles;

but they must not be mistaken for the tracks of these particles. One may not, for example, say that a point traverses its world-line; or that the three-dimensional section which represents the momentary state of the acual present, wanders along the time-axis through the four-dimensional world. For a wandering of this kind would have to take place in time; and time is already represented within the model and cannot be introduced again from outside. Hence, those arguments, according to which the four-dimensional description of the world proves the unreality of time and depicts the world as rigid motionless existence, are absurd. On the other hand, there is much to be said for designating the four-dimensional world as absolute in contradistinction to three-dimensional representations with added time specifications, for these latter contain more arbitrary features and in consequence are relative to the methods of description. In comparison with the four-dimensional descripion, these behave like the image in perspective of an object as compared with its plastic reproduction. The method of investigation of relativity theory (which could with more justification be called *absolute* theory) does not allow of any scope for subjectivity or arbitrariness on the part of observers. On the contrary, this theory demonstrates a greater objectivity than any of the former methods of description.

We distinguish between a kinematic and a dynamic meaning of the word "motion". In the first interpretation, motion is defined as change of position in time; and since data concerning position can only be given relatively to a frame of reference, motion according to definition is relative. In the case of the dynamic interpretation on the other hand, motion is defined by the

way in which it occurs in the laws of nature; and in this context it might be quite possible that coincidences with a definite body (Neumann's body α) play a part in all the laws of motion. In that case, these bodies would have to be described as "being in a state of rest", and the motions referred to them as "absolute" because they would be distinguished in accordance with natural laws. Thus, when the general theory of relativity maintains that all motions, even in the dynamic sense, are relative, this is not a tautological, analytical proposition, but a statement of the fact that no frame of reference has a privileged position with respect to any arbitrary motions.

In the physics of Newton on the other hand, although no single frame or body was selected, a certain group of them was singled out—namely all those which were either in a position of rest relative to the fixed stars, or in a state of uniform, rectilinear motion. We call the latter group of systems of reference, Galilean or inertial systems; and relative to this group, the principle of inertia in the Galilean form as well as all the other laws of Newtonian physics are true. Later, the "aether of space" became the sole privileged frame of reference and lost this distinction when it transpired that all Galilean systems of reference are equally valid for all mechanical as well as for all electro-magnetic processes (propagation of light) (Einstein's special theory of relativity 1905). The impossibility of speaking of coincidences with aether particles and hence of their genetic-identity, showed that the concept of substance is inapplicable to the vacuum—a result of great philosophical significance.

Accelerated or curvilinear motions have an absolute

character both in Newton's system and in the "restricted theory of relativity" of 1905. Only the "general theory of relativity" of 1915 abolished this absolute character and with it the privileged position of special groups of bodies, and thus led the way to a more satisfactory fulfilment of causal requirements. Neither in Newton's system nor in the special theory of relativity was any reason given for the special distinction of inertial systems.

In order to achieve this, Einstein had to try to formulate the law of inertia in such a way that no reference was made to a special group of bodies (an inertial system), but only to the actual configuration of existing bodies. An indication that this was possible consisted in an extremely striking fact which had been neglected by the physics of that date—namely that the measure of the inertia of a body (its inertial mass) is exactly equal to the quantity which measures the effects that are solely dependent on the configurations of bodies, the so-called gravitational effects). On the strength of this fact, Einstein succeeded in discovering a law which includes both gravitational and inertial phenomena (and showed that both are essentially the same). In consequence not only are all special reference frames eliminated, finite systems abolished, but a tremendous simplification of the world picture is achieved.

Foundations of the General Theory of Relativity

The new law of motion is a differential law—in other words it represents the motion of a particle as dependent, not on the configuration of the world, but solely on the measurable relations prevailing in its immediate neighbourhood which, in turn, are only

indirectly conditioned by that configuration. Thus, the law of motion expresses a relation between the motion of a particle and the result of the measurements of time and lengths which are supposed to have been taken in its immediate neighbourhood and which are usually designated as propositions concerning the prevailing "curvature of space" or "gravitational potential in that neighbourhood".

It cannot be sufficiently emphasized that this reference to the actual method of measurement constitutes the only way of understanding the meaning of the world picture as sketched above.

In order to establish coincidences, the genetic-identity of material points is assumed, at least for short intervals; and no strict distinction between real coincidence and close proximity can be made. Furthermore, all the experiences of coincidence are united by a continuous field of perception. The world of experience is thereby given a very special structure which can, perhaps, be formulated by saying that a particular physical significance is ascribed to the concept of immediate proximity; or that, in other words, a definite order of magnitude of lengths is actually privileged, within which it is not really possible to speak of any arbitrary deformations. The description of reality with the help of the four-dimensional schema is a result of the construction of physical space from psychological spaces (visual and tactile spaces etc.). These latter are, however, by no means relative. In small regions of these spaces, both lengths and motions can be spoken of in an absolute sense and not as though founded on coincidences. In these regions, the application of Euclidean geometry is more than an arbitrary convention. Never-

theless, the question as to which geometries shall be constructed for greater or smaller magnitudes, that is, for atomic or astronomical dimensions, is no longer psychologically, but purely physically, determined.

CHAPTER EIGHT

A CRITIQUE OF CONVENTIONALISM

THE LAW of inertia states that a body left to itself, traverses equal distances in equal times.

A purely psychological time-computation is not sufficient to determine what is meant by "equal times", because we know by experience that it does not result in exact or objective propositions. In science, therefore, the measurement of time, with the help of the concept of motion—and preferably of periodic motions—is reduced to measurement of space. Our unit of time then, is first of all determined with the help of a concrete definition—namely with that of the period of the earth's rotation. This definition is not entirely satisfactory, since it prevents us from speaking of a retardation of the earth's rotation. The fact that astronomers assume this retardation proves that they start from another definition of the time unit—namely from the convention that the time unit must be chosen in such a way as to simplify as far as possible the formulation of natural laws.

When the laws of nature are applied in this way in the definition of fundamental concepts, it appears almost as though they themselves had become mere definitions, or arbitrary conventions, which tell us nothing about reality. The view according to which all the laws

of nature are mere tautological conventions, is known as "Conventionalism". We will take the law of inertia as an example to make the error of this conception quite clear. Although "equal times" are defined as those periods of time in which a body left to itself traverses equal distances, the sentence "every body left to itself traverses in equal times equal distances" is not tautological; it contains the statement which can be empirically proved, that *all* bodies when left to themselves exhibit a definite quantitative regularity in their motion. (The ratio of the distances traversed between two points or instants of time is constant for each of two such bodies). In order to establish the truth of this law, the concept of the simultaneity of two coincidences is required, but *not* that of the equality of times. Thus the latter can be established in such a way as to give the described regularity a particularly simple expression; and the convention consists in exactly this.

There would appear to exist another possibility of maintaining the conventionalist interpretation—namely if the concept of the "body left to itself" be analysed. A body of this kind must be regarded as one which is not acted upon by any force. But how is this fact of the absence of forces to be recognized? Only through the fact—so it is argued—that the motion of the body is rectilinear and uniform.

But if this definition of the body left to itself be included in the formulation of the law of inertia, the latter really becomes a tautology. The error in this reasoning is due to the idea which, in itself, is quite correct, that a physical quantity or magnitude can be defined by the type of measurement to which it is subjected. And since forces are measured by accelerations

—that is by the degree of change in rectilinear, uniform motion,—one is led to believe that the discovery of a deviation from this type of motion is identical with the assertion of the existence of "forces". But this view is an erroneous one, inasmuch as it ignores the empirical fact that these changes only occur when other bodies exist in the neighbourhood or proximity, of the experimental body. Thus, we must define bodies left to themselves as those which are at a sufficiently remote distance from all others. Then the law of inertia becomes a significant proposition concerning natural processes. For a complete explanation of the error, an understanding of the meaning of the concept of force is necessary.

Before attempting to achieve this understanding, we will first mention very briefly the foolish attempt that was made to explain the law of inertia by the principle of causality. Obviously, we cannot conclude that velocity must remain constant so long as no cause exists to change it. For in that case, we would be equally justified in coming to the conclusion, that acceleration or position must be constant. (The latter would correspond to the reasoning in antiquity). But any argument which leads to contradictions is false.

The concept of force obviously originated in the experience of the exertion which is necessary to set a body in motion and whose intensity depends on the nature of the body. In formulating a law of motion to account for such experiences, physics attempts to describe the motion by means of a quantity which is solely dependent on the total configuration of the bodies concerned; and it has discovered such a quantity in the product of two factors, namely the accelera-

tion of the test body and a constant characterizing it, known as its inertial mass. Thus, the equation: $C = m.a$ is not a mere definition; its meaning is expressed by the proposition: "the quantity m.a is a function of position which is solely dependent upon the constellation of the participating bodies and which becomes zero when the masses are at a great distance". (The latter subordinate clause expresses the law of inertia).

We will take the principle of energy as a second example in our discussion of conventionalism. Since the energy (E) of a system referred to a certain initial state (I) cannot be measured otherwise than by the amount of work (W) and heat (H) given off by the system when it is converted from state (I) to another state (II), the equation $E = H+W$ appears to be nothing more than a definition of the quantity E. But this is by no means the case. On the contrary, this equation expresses the empirical fact that the sum of the work and heat given off depends solely on the conditions I and II, but not on the manner of transition. This fact which accounts for the impossibility of the perpetuum mobile is the only reason why that sum is distinguished by the special name of energy.

The examples dealt with here, show that the psychological reason for the conventionalist error is the failure to realize that the formulae of physics in themselves, do not express natural laws, but only when they are combined with explanations of the meaning of the quantities occurring in them. It is true that in a purely formal way one can, with the help of a convention, declare some sentence to be true by simply requiring that, for example, spatial relations must be

described only in a Euclidean manner; or that matter must be conceived as consisting of spherical atoms. But it is an error to suppose that such sentences represent laws of nature.

On the contrary, a true law, a genuine proposition about nature, only occurs if it is at the same time stated what additional sentences or auxiliary hypotheses must first be added in order that the proposition may agree with the facts of observation. To express this schematically: I can equally well make the convention C_1 or the conventions C_2 and so on as the basic principles for the description of nature; but none of these say anything about the world. A true sentence about nature is only given by the proposition: "Assuming C_1, one must add the sentences S_1. . . , in order to remain in agreement with experience". Or the proposition: "Assuming C_2, one must add the sentences S_2 . . .". There is involved here a confusion of "sentence" and "proposition". A sentence only becomes a proposition through the addition of definitions (statement of its grammar). The sentence S_1 with the conventions C_1 may represent the *same* proposition as the sentence S_2 with the conventions C_2. The mere sentences or formulae are, like all signs, conventional; but they are not natural laws. These are only contained in propositions, the meaning of which is given by sentence +convention; they are no longer, in any sense, arbitrary.

CHAPTER NINE

FUNDAMENTAL IDEAS OF THE SPECIAL THEORY OF RELATIVITY

THE CONCEPTS of spatial and temporal magnitude are not yet included in the concept of coincidences; but are only constructed from it. And for this, as we saw, new definitions are required, both in the case of spatial magnitudes and in the definition of the equality of times. The concept of simultaneity at different points which was then assumed, is only derived from the notion of simultaneity at one point.

The latter will not be more fully explained; it is a name for a certain type of experiences. The temporal order of remote events can only be determined with the help of signals. Einstein realized that the principle whereby this is determined is equivalent to the definition of simultaneity. The two empirical data: first, that an infinite velocity of signals does not exist, and secondly, that the special principle of relativity is true, lead to a relative concept of simultaneity which is, of course, absolutely non-contradictory. It would be possible to retain an absolute concept of simultaneity if, by concrete definition, one were to select some body arbitrarily as frame of reference and assert that all measurements referred to it are the "right" ones. But 1) this would be entirely arbitrary and could not be

reproduced; and 2) it would necessitate the introduction of new hypotheses (such as that of the Lorentz contraction, for example) to explain why that system of reference is not characterized by any distinctive experimental traits.

On the other hand, the introduction of relative simultaneity is much simpler and conforms to the principle according to which only observables are to be included in the formulation of the laws of nature. It thus becomes possible to recognize an absolute order in nature and to distinguish in it what depends on the method of description (measurement). A certain order of coincidences with space-like and time-like differences is absolute. On the other hand, the way in which this order is subdivided into spatial and temporal intervals, depends on the system of reference—that is on the methods of description.

The impossibility of finding a privileged system of reference, makes it equally impossible to regard the "aether" as a system of reference, or to ascribe to it a state of motion. Hence the aether loses its character of a substance. The world does not consist of substance, but of a system of ordered events or occurrences. The interval between two neighbouring occurrences or events in the four-dimensional representation ($ds^2 = dr^2 - c^2dt^2$ as an example of positions not affected by gravitation, where "dr" is the spatial, "dt" the temporal interval between two events) is characteristic of the objective or absolute order of the world. Thus, the velocity of light c is essential for spatio-temporal order: it makes possible the uniform relations of the world so that all causal order is based on it.

CHAPTER TEN

THE PRINCIPLE OF CAUSALITY IN CLASSICAL PHYSICS

THE PRINCIPLE of Causality, as usually formulated, states that every event is the effect of a cause. The content of the concepts cause and effect cannot be strictly transcribed because natural events cannot be isolated. Hence, the words "cause" and "effect" do not occur at all in the laws of nature; instead, we have the interconnection of events expressed by mathematical functions. Every event is interpreted as a change of state; every state is characterized by certain magnitudes and every law of nature states a relation between these changes in magnitude which describe various events. The changes in magnitude, wherever possible, are assumed to be infinitely small, in which case natural laws are expressed in the form of differential equations.

Since the differential laws are micro-laws which cannot be directly verified, caution is necessary in judging the value of this method for knowledge. Nevertheless, it corresponds to the empirical fact that all the effects observed are contiguous effects—that is to say that whenever one event is shown to be dependent on another at some spatio-temporal distance from it, there

are always other events between these which also depend on them, and moreover in such a way that a greater temporal interval corresponds to a greater spatial distance. Thus, the typical law of nature in classical physics is a formula representing events at one point in their dependence on events in the immediate neighbourhood, namely the "field-equation" (by "field" we mean a spatial region the state of which at every point is completely determined by the values of certain quantities). In field physics, the attempt is made to describe all events by means of these quantities and hence, to express,—for example,—the atomic and electronic processes also by mere field equations. The best known field equations were formulated by Maxwell for electro-magnetic processes. But they are certainly not true for regions of any degree of smallness whatever. The theory of the vortex-ring atom was also a type of field physics.

From this point of view, the principle of causality appears to be easy to express in the four-dimensional description of nature. It seems to assert that the inside of a four-dimensional cylinder is completely determined by any section of any desired degree of thinness, in the time-direction and by the cylindrical surface (boundary conditions) or alternatively, by two purely spatial sections and the surface. Accordingly, although as a result of the structure of the space-time manifold as previously described, time-like directions possess a privileged function, the past-future direction has no preferred role in comparison with the future-past direction. Thus, it is exactly the same whether we say that the past determines the future, or the future determines the past. But what does the word "determine"

mean? The meaning of both the principle of causality and determinism depends on just this. The causal determination of one event by another is without doubt a real connection between the two; but this only means that between the two, other dependent events can always be discovered. Nevertheless, we must agree with Hume in maintaining that the search for a causal link, or cement of some kind between two events, is a meaningless one.

The inquiry as to whether causality exists can only be interpreted as the inquiry whether a natural law exists. The principle of causality itself is not a law; it only expresses the fact that laws exist. And since it makes no difference whether I simply state a natural law, or whether I add to the statement the phrase "this natural law exists", we encounter logical difficulties whenever we try to formulate the law of causality as a statement that laws exist.

"Events take place in conformity to law" appears to mean that formulae exist which, with the help of a four-dimensional cylinder, permit us to calculate from a given special section the remaining sections. But once the four-dimensional representation of events is given, it is always possible to discover formulae which perform this task. So that if law were to mean nothing more than the possibility of representation by means of functions, every conceivable natural event would take place according to law; and the principle of causality which asserts the regularity, or conformity to law, of nature, would be an empty tautology. In order to give this principle a content, the attempt is usually made to impose limiting conditions on the functions, either by requiring them to be simple, or by stipulating that

no space-time co-ordinates should occur explicitly in them. This last criterion, used by Maxwell in his definition of causality, is identical with the sentence: equal causes, equal effects. For it states that the result of a natural process is always the same, independently of both the time and place of its occurrrence. Actually, both criteria are fulfilled in every law of nature (although "simplicity" is a very vague concept); and they could therefore be considered as sufficient in practise for a definition of regularity or conformity to law. Nevertheless, the situation is not logically satisfactory, inasmuch as it is possible to imagine neither of the criteria being fulfilled and in spite of this, events being still regarded as causally determined. This would be the case, if one were in possesion of formulae, no matter how they functioned, which always supplied correct predictions of events. As a matter of fact, the fulfilment of predictions is always the decisive criterion for the existence of causality; it is, however, of a purely practical nature and thus not suitable for a logical formulation of the principle of causality.

Classical physics is deterministic. And according to determinism, the future can be completely predicted from the present. Determinism has nothing to do with the truth of the law of contradiction in respect to propositions concerning the future—as Aristotle, and also modern logicians, believed[20]. According to the law of contradiction, every proposition about the future is either true or false. According to determinism, its truth or falsehood can be deduced from propositions about the present—which is quite a different matter.

CHAPTER ELEVEN

THE STATISTICAL METHOD OF INVESTIGATION

IN CLASSICAL physics, the relation of causality is always regarded as being a one-one relation. But the possibility of its being a many-one relation in which several different events W_1, W_2 and so on, to W_n would be regarded as effects of the same event U, must be taken into consideration. This would involve a certain limited order in nature within which various different types can be distinguished as follows:

1) n is finite; 2) n is infinite, but the W all occur in a finite domain; 3) n is infinite, the W do not occur in a finite domain, but possess points of accumulation in such a domain. Here, we have various degrees of order; and the question now arises as to when it is permissible to speak of any order whatsoever. It would appear as though the answer to this question must provide a definition of regularity or conformity to law, since it would simply be the negation of complete irregularity. But the calculus of probability gives us the definition of irregularity: Where a certain average distribution of data occurs in a very extensive series of

observations, we say that *no* order exists. Expressed vaguely, this is the kind of distribution in which, out of the totality of possibilities none are distinguished. This is formulated by the calculus of probability; and in answer to the question as to how it is possible to apply this calculus to reality, we say that only the absence of conformity to law—or irregularity—is defined by its truth. Since the strict truth or validity, of the rules of probability requires its application to infinitely many cases which in reality do not exist, we do not by these means obtain a strict definition of conformity to law. As we have said, irregularity prevails within the space-like levels of the four-dimensional world, whilst order in the direction of the time-like fibres is stated by causal laws. In other words, only laws of succession, but none of co-existence, exist.

Classical physics applies this to the kinetic theory of heat; when it states the initial conditions of a definite volume of gas, for example, where the distribution of the momentary positions and velocities of the molecules is assumed to be totally irregular. On this assumption, it is calculated that for such a host of extremely numerous molecules (where the molecules are treated as elastic spheres obeying mechanical laws) the most probable behaviour is just that which corresponds to the empirically discovered laws of gases. A special result is the validity of the so-called law of entropy—that macro-law, which, because it says something about the direction of the macroscopic processes of nature, plays a very important part in physics.

The classical micro-laws, both of mechanics and electro-dynamics, do not permit of any distinction between the time-direction earlier-later, and its opposite.

Hence, the only alternative is to make the initial conditions in nature responsible for the privileged direction from past to future. And this results from Boltzmann's interpretation of entropy which appears to be, as it were, a measure of molecular disorder. The number of conceivable molecular distributions which correspond to a macroscopic state of greater entropy, is far larger than the number of distributions which are the result of a macroscopic state of lesser entropy. Given a state of lesser entropy, it follows from the assumption of molecular disorder—indeed, this assumption states nothing else—that the transition to a state of greater entropy, has a greater degree of probability than any other event. Thus, the law of entropy is a law of probability, which formulates only the existence *of irregularity of lawlessness in the space-like directions* (it thus expresses the non-existence of laws of co-existence).

If the law of entropy had the strict validity that is usually attributed to other laws of nature, the cosmic processes of the birth and death of stellar systems would not be of a cyclic nature as the doctrine of eternal recurrence in its most extreme form maintains, or as Arrhenius depicts it. But if the law has only a probable validity (and that this interpretation is the correct one is rendered plausible by the phenomenon of the so-called Brownian motion), then natural processes are no longer irreversible in principle, and the greater the lapse of time, the greater is the probability that processes also occur in the world which take place in the direction of decreasing entropy. If the universe were finite, this would be true of the whole cosmic process, and time could interchange the past and future,

and unroll in the reverse direction. But an investigation as to how far such a way of speaking has meaning, would take us too far at this juncture[21].

CHAPTER TWELVE

THE FUNDAMENTAL CONCEPTS OF THE NEW PHYSICS

THE STRUCTURAL foundation of the concepts used in classical physics consists of coincidences which are held to be directly observed. They are, however, in reality constructed from certain perceptual experiences and can only be regarded as objective results of observation in so far as there is the possibility of making a strict distinction between the observed occurrence and the methods of observation. Strictly speaking, a completely accurate differentiation is not possible, even in the classical theories, because of a reciprocal action between the two which always disturbs the observed occurrences. But since, on principle, this disturbance can be made arbitrarily as small as desired—provided that the reciprocal action be continuous—a sharp distinction could, at least theoretically, be made. But this is no longer possible if the reciprocal action be discontinuous,—that is if in every natural process—and observation is itself a natural process—a finite quantity of energy be exchanged. That this exchange actually takes place, is the basic principle of the quantum theory, according to which, therefore, the concepts of observation and of an objective description of nature, are both

problematical; so that the old philosophical problem of the difference between subject and object reappears here in a tangible form. The decision as to what belongs to the process of observation and what to the process observed is, within certain limits, arbitrary. Thus difficulties arise, for the solution of which a new system of concepts that must of course retain its connection with sense perception, is required.

This discontinuity of natural events which is the basic fact in quantum theory was first discovered by Planck in connection with the processes of radiation. His conclusions led to the hypothesis, which was later confirmed beyond any doubt, that a frequency ν only occurs in quanta of energy of magnitude $h\nu$ where the so-called Planck quantum of action h is a universal constant of which the value in the usual system of measurement equals $6{,}55 \cdot 10^{-27}$.

The idea of the quantum-like propagation of light is incompatible with the former conception of continuous spherical propagation for according to the latter, the density of radiant energy at great distances from the source of light, would become arbitrarily small, whereas according to the quantum theory, smaller quantities of energy than $h\nu$ do not exist.

All the experimental apparatus for the observation of interference phenomena demonstrate the wave-like character of light in agreement with classical optics, while other experiments show just as clearly the corpuscular nature of the radiation. One might presume the existence of two different kinds of radiation; but this hypothesis cannot be accepted inasmuch as the reason why one type or the other occurs, does not depend on the origin of light, but on the way in which

it is observed. The hypothesis whereby the source of light emits, so to say neutral entities, which are only given definite form through being observed or registered, is likewise unacceptable, because the very meaning of the distinction between wave and corpuscle denotes a diversity in the propagation. These difficulties in describing the propagation of light correspond to the difficulties encountered in the attempt to render the absorption and emission of quanta intelligible by means of Bohr's model of the atom. For this model only furnishes an abstract relation between the energy values of the electrons rotating within the atom and the frequency of the emitted radiation. And while this relation enables us to make predictions—which are brilliantly confirmed—concerning the structure of the spectrum, it leaves us completely in the dark as regards the process of emission and absorption of quanta by the atom. It only permits us to state that the occurrence of these processes obeys no laws—in other words that it is only governed by the rules of probability. The duality of waves and particles which is manifested in radiation, was raised to the status of a general principle in the description of nature by de Broglie who thought that to every corpuscle of mass m (which according to Relativity theory has an energy content of mc^2) a wave must be associated of which the frequency ν is determined by the relation $mc^2 = h\nu$[22]. Soon afterwards, experiments confirmed the fact that corpuscular rays actually possess the characteristics of waves of the predicted frequency. Hence, this dual nature was established as a universal attribute of fundamental physical concepts, and was called "complimentary" by Bohr.

The contradiction between these two interpreta-

tions (neither the experiments nor the facts are mutually contradictory—only the interpretations) can only be eliminated by the renunciation of perceptual images in the case of small-scale or microscopic processes. The philosophical view that the meaning of natural laws can only consist in the formulation of regular connections between the data of observation for the purpose of predictions, caused W. Heisenberg to renounce all perceptual models and to search for a mathematical formalism which would achieve the desired results, and by means of which the atomic states which could not be interpreted by spatio-temporal methods, could be diagrammatically characterized by purely formal numbers. Another, apparently quite distinct, theory was produced by E. Schrödinger. This is a "wave-mechanics" from which the truth of the classical mechanics for large-scale phenomena can, as a limiting case, be as easily derived as geometrical optics from wave optics. In this theory, a certain quantity ψ which satisfies the so-called Schrödinger wave-equation, appears, but is omitted again in the final results which can be directly tested. Schrödinger himself interpreted ψ as the measure of the electrical density at each point —an interpretation which does not seem to be practicable. On the other hand, Max Born's interpretation in which the value of ψ at one point is considered to be the measure of the probability that a corpuscle or a light-quantum is to be found there, is more acceptable. Accordingly, that which is propagated in waves is not physical reality, but the measure of a probability. To this we must add that the propagation of the ψ waves does not take place in ordinary space, but in the so-called configuration space, a mere graphical,

auxiliary structure of as many dimensions as there are independent co-ordinates. The whole thing is an extremely abstract method of estimating the probability of the occurrence of certain events—and not a model.

Later it turned out that the theories of Heisenberg and Schrödinger, in spite of the total diversity of their form, are yet in complete physical agreement—in other words, they each give rise to the same propositions about reality. This is an important illustration of the universal truth that the essence of a theory consists solely in its logical structure, while its symbolical or perceptual dress is quite immaterial as regards its explanatory value.

The ideas of de Broglie and Schrödinger originally arose from a desire to reduce all the corpuscular characteristics of nature to those of waves, and thus to regard corpuscles and their motion as illusory, so to speak; or as the points at which trains of waves interfere in a very peculiar way (the so-called wave-packets). Max Born's view, on the contrary, would seem to be an attempt to regard only the corpuscles and quanta as real and the waves merely as auxiliary constructions. The question as to which theory is the correct one has no physical meaning. In any case, the distinction between quanta moving with the velocity of light and corpuscles moving at a lesser velocity, remains. The latter have a so-called stationary mass, which the former do not possess. The waves which according to de Broglie are associated with a corpuscle moving with the velocity v have the velocity of propagation $w = \frac{c^2}{v}$, which is thus greater than that of light. But

since this does not deal with the real propagation of an effect, it is not contrary to the theory of relativity. On the contrary, these new ideas permit of the assertion that only one real velocity exists in the world with which all effects are propagated; and that all other motions are either illusory, so to speak, or are secondary in character, like the motions of waves on the surface of water which must not be mistaken for the real motion of the particles of water.

CHAPTER THIRTEEN

CAUSALITY IN THE NEW PHYSICS

THE FACT that neither the corpuscular nor the wave conceptions by themselves yield an intuitive or pictorial model of events, but that instead, according to the circumstances sometimes one and sometimes the other of these mutually exclusive descriptions appears to be the most practicable, finds its expression in the essential impossibility of completely accurate observations. Heisenberg's uncertainty relation sets a limit of this kind to all exactitude in measurement, inasmuch as an increased accuracy in the measurement of any one element or part of nature (such as the position of an electron for example) involves, in conformity to law, a decrease in the accuracy of the measurement of another element or part (the velocity of an electron for example). The product of these two accuracies is of the order of magnitude of a quantum of action. This universal law is derived from the fact that the effect, or influence, of an observation cannot be made arbitrarily as small as desired, so that a sharp distinction between the two is impossible to maintain. Hence, it is impossible to say that the state of a system can ever be accurately determined by measurement. But since a determination of this kind is a prerequisite

for the strict application of the principle of causality, it follows that modern science must renounce the exact truth of this principle and be satisfied with predictions that have probability. Science is thus no longer deterministic in character.

* * *

These sentences conclude the Philosophy of Physics as left by Schlick. The handwritten manuscript only contains in addition the note: "Problems of Biology" and instructions concerning these investigations.

CHAPTER FOURTEEN

THE FUNDAMENTAL PROBLEM OF BIOLOGY

THE PHENOMENA of organic nature must also be described by laws. There is no doubt—and this is universally recognized—that the laws of nature, of which we have spoken hitherto, are equally true for organisms. Nevertheless, some philosophers and biologists maintain that in addition to these, other specific laws are effective in living creatures and that there is, for instance, a special type of energy which is peculiar to all things living and which is not manifested in the inorganic world. This theory of the autonomy of life is called: "Vitalism". The opposite point of view, that all biological laws can be reduced to physical principles is known as "Mechanism", inasmuch as it was thought that physical could be reduced to mechanical processes. To-day, the designation "mechanism" is no longer a suitable term; it would be better to speak of "physical interpretation".

Biologists are, however, still inclined to regard physical processes as simply mechanical; and if an insufficient description of biological occurrences is obtained on this basis, they tend to resort to vitalism.

At the end of the last century, the "mechanist" theory was predominant. At the present time, the view

is widespread that biological laws cannot be reduced to physical principles. In order to indicate as clearly as possible the direction in which the solution may be found, we shall start by endeavouring to obtain criteria which will help us to decide whether life is present in a given case or whether it is not.

CHAPTER FIFTEEN

THE CRITERIA OF LIFE

IN ORDINARY life, the differences between organic and inorganic nature are easily recognized. But there are cases in which we cannot—or only with great difficulty—determine whether something, such as a seed for example, is living or not. If the seed is old, we have to plant it before we can see whether anything living will grow from it. For so far, it has not been possible to substitute microscopic criteria for these rough tests; and, hence, in biology the latter are usually applied. We shall illustrate this by a few examples:

William Roux, the founder of the so-called developmental mechanics says: A body is living if it possesses the following characteristics: 1) metabolism (substances are absorbed, assimilated, dissimilated and separated); 2) Growth; 3) Active movement (the attempt is made to achieve a more exact definition here, by including in it the concept of "irritability" or in other words, of "sensitivity", in order to differentiate it from the reactions of inorganic bodies); 4) Reproduction (increase, or multiplication); 5) Inheritance (similarity, or likeness between parents and children). This is a variegated jumble of aspects which do not however

suffice for a decision, in each individual case, as to whether a given body is living or not.

The following definitions are likewise far too general and in consequence inadequate. "Life exists wherever there is evidence of a certain instability" (Dubois-Raymond). "Life is present wherever the peculiar phenomena of movement which characterize life, exist" (Haeckel). This is a circular definition. "Life is the continuous adaptation of internal and external conditions" (Spencer). In answer to the latter: the same thing can be said of a physical machine. "Living bodies are capable of controlling automatically those stores of energy which are necessary to them for the stationary maintenance of their state" (Ostwald). Here we ask: in what does this automatic control consist?

Furthermore the attempt was made to deduce the existence of life from more obvious attributes—such as the shape of the body for example,—which should indicate whether it is, or was, living. From the standpoint of morphology, all living creatures are composed of cells. Once we know what a cell is, we possess thereby, one of the criteria of life. But only very rough characteristics can be specified, even for cells. And even if a cell could be exactly defined, there would still remain the problem of how to distinguish a living from a dead cell. Hence, we must first of all examine, individually, the processes which take place within the cell itself. Only then can we solve the problem as to whether processes within the organism take place in accordance with purely physical laws.

Pasteur attempted to draw a sharp line between the living and the non-living by showing that no proof exists of life having developed from the non-living. A

further distinction between the organic and the inorganic was thought to have been discovered in the fact that certain chemical compounds only occur in living bodies. Accordingly, it was thought to prove that life is a process which produces these so-called organic compounds. Organic chemistry was set in opposition to inorganic chemistry. But when, in 1828, a certain organic substance, called urea, was produced from inorganic substances, the view that the difference between the organic and the inorganic is due to the nature of their constituents, could no longer be maintained.

Many organic substances are differentiated by their extremely complex composition which makes it extraordinarily difficult to synthesize them. Even the simplest proteins, which are essential for the formation of living substance, exhibit great complexity. In order to gain insight into the innermost part of living processes, we should have to observe these processes while metabolism was taking place within the molecules. It is not surprising, therefore, that amongst living processes some are found which are extraordinarily different from those that we come across in daily life,—as in the case of sensitivity e.g. What is probably only quantitatively different, gives at first the impression of being essentially distinct. The complexity is nevertheless physical in quality; and this shows what an important part is played by the physical.

Since it is impossible to determine, on the basis of either constituents or form, the essential difference between the living and the non-living, it can only be discovered in processes. In living protoplasm, processes take place which differ from those occurring in dead

protoplasm; but our knowledge of what these processes are, is not yet sufficient.

According to what we have just said, the differences between the organic and the inorganic are given provisionally by macroscopic criteria: and the biologist can begin with these. What we need is a criterion which can, at any moment, be applied to any body—to a seed, for instance. If we knew the ultimate microscopic process, we should also know whether organic substances obey organic laws exclusively, or whether they conform to others as well. Only then could we decide whether these laws would permit of the development of organic out of inorganic substance. On the other hand, if we only knew where and when life originated, we should still not be in a position to solve the question as to whether the processes in living substances obey purely physical laws.

Thus at the present stage of research, we cannot say what the essential quality is which differentiates an organic from an inorganic body. The differences can only be discovered if a thorough examination of the phenomena of life be undertaken. And this method may not make use of shortcuts. Formerly, shortcuts of the kind were always being attempted without, however, anything being known of what takes place in the smallest region of the living organism. It was believed that the discovery that living substance could be produced from the non-living would prove that organic substances obey physical laws only. But even that would not be a compelling reason. And even if it were possible to produce living substance in solutions, we should not be much wiser as regards the main issue. For the creation of living substance in this way,

would only be an indication but no proof, that life obeys physical laws exclusively. In order to decide this question, we should have to be in possession of exact knowledge concerning the process whereby the living germ originates in the solution.

CHAPTER SIXTEEN

VITALISM

AT THE time when it was still believed that diversity in constituents is what differentiates the inorganic and organic domains, it was also thought that a special type of force, known as the life force, existed in all living bodies and was the source of the specifically organic compounds. This was the *"older vitalism"* in which, however, nothing was said about the regularity, or conformity to law, of this life force; it thus only amounted to an assertion that organic and inorganic substances are inherently diverse, and was not a scientific theory.

Later, an attempt was made to replace the life force by something of greater philosophical significance. A form of modern vitalism maintains that life is distinguished from the non-living by the fact that it includes consciousness (soul). This is the theory of "psycho-vitalism". Now, there are philosophers who believe that, essentially, all things are conscious; and if this were true, the distinction made by psycho-vitalism would obviously be no longer tenable. But even if this pan-psychism be repudiated, the definition of life with the help of consciousness is certainly an impracticable one. Those states known as sleep and unconsciousness,

seem to prove the falsity of the assertion that life and consciousness are interdependent. Against this, it could of course be objected that in the aforementioned states only the central consciousness is lacking; and that, on the other hand, the cells continue to have consciousness. But these are wild speculations. The fact remains that biological research does not regard the phenomena of consciousness as criteria of life.

The difference between the organic and inorganic worlds can only consist in the regularity of processes—a fact which the new biology has recognized.

And even where attention is concentrated on constituents, the idea still prevails that the essence of life is to be found in a special form of law to which living substances conform. Thus, a theory of Verworn's contends that life is connected with a complex substance unknown to us, to which the peculiar type of behaviour known as sensitivity is attributed. This substance, by virtue of the special constellation of the atoms, is supposed to manifest the characteristics of life. Here it is not a question of a substance in the proper sense, since it is supposed to be distinguished by a special type of conformity to law. This theory which might in itself be acceptable, is still undecided because we have no clue in our experience whereby to test it. According to this theory, therefore, a different composition distinguishes living from dead protoplasm.

What can we say about the form of the laws which govern the organic world? First of all, in answer to the question as to whether the laws of the organic and inorganic worlds are the same, proposals have been made which cannot possibly lead to a solution.

Many began with the principle of energy and have

asked whether it be true in the case of organisms. Although this is undoubtedly an important issue for science, an investigation of the kind has not much significance for philosophy. For since we know by experience that the organism is not a perpetuum mobile, it is improbable that the organic world does not obey this principle. Experiments have now shown that the principle is actually true for living bodies. The first experiments which led to this conclusion were carried out by Rubner in 1894 on animals, and by Atwater in 1904 on human beings. On the whole these experiments have established the truth of the energy principle in the case of living creatures. But since only the initial and final effects of energy, over longer periods of time were compared, it is possible that in shorter periods, energy might be both created and destroyed. No conclusions regarding small-scale events can be deduced from these large-scale observations.

In connection with these researches, the view that in living creatures a special type of energy, known as vital energy, exists, was defended by the representatives of Energetics. This view would not have any scientific importance even if the theory of energetics were not already out of date. The hypothesis of a vital energy would only be a reasonable one if a method of measurement for it were known; but no trace of such has ever existed. It is quite impossible to single out vital energy as a specific type of energy. And even if a special vital energy were to exist, biology would then only be a special branch of physics and we should still have no right to oppose organic and inorganic laws. The distinction would merely be of the same kind as that existing between the separate branches of physics.

The efforts of certain biologists are directed towards the discovery of some element in the laws governing living creatures which does not occur in the inorganic domain. This element, in combination with the concept of purposiveness, is regarded as a special feature characterizing organisms. With their conception of teleology, the majority of vitalistic biologists pursue a line of reasoning which impedes their return to the physical domain. Their arguments are roughly as follows: The ultimate aim of all organisms is the preservation of the individual and of the species.

All processes within the organism are interlocked in such a way as to make the preservation of the organism possible; their regenerative capacity may be regarded as an example of this. But we find nothing similar in the inorganic world where there are no organisms (individuals). We might of course, look upon a planetary system as an individual, or even as an organism, with regenerative capacity,—where this word would designate restoring capacities in the case of disturbances, as in the case of the passage of a comet for example. But in organisms, the capacity of self-preservation goes much further. The processes within an organism are tuned-in to one another, and in case of injury, certain processes which remove the damage start to function automatically. These processes may be called teleological. Now, many biologists have asserted that the concept of teleology involves that of purpose. But "purpose" is an end effect of action which is anticipated in consciousness. Hence, to speak of "purpose" is only significant where there is consciousness. As a matter of fact, some vitalists maintain that teleology is only present where consciousness exists; and hence

that consciousness must be ascribed to organisms. To this we can object that it is possible to define the concept of teleology and to apply it even where no purpose is presumed. Observation can only tell us that when the equilibrium of an organism is upset, certain processes are set in motion in the affected organism in such a way as to result finally in the preservation of the organism, or species, from outside disturbances. And this fact served as a basis for the attempt to discover an essential difference between machine and organism. It was also Driesch's idea; and in order to characterize the aforementioned processes, he called them "psychoids". The usual argument is as follows: a machine is so constituted that each part of it fulfils only one definite function which breaks down as soon as a part is damaged; an organism on the other hand, builds up the damaged parts anew. It is not possible to construct a machine so that the different parts can replace one another; each part has its function and cannot undertake those of other parts. To this we may remark that, even when we have defined the machine in this way, we have only defined what we mean by a machine; we have not *stated* anything thereby. The assumption that it is impossible to conceive of a physical system which operates exclusively in obedience to physical laws, but which, at the same time, possesses the regenerative capacity of an organism, remains unproved. There is no universal super-principle from which the impossibility of such an instrument or apparatus could be deduced—there is not even the semblance of such a proof. One need only imagine our instruments as constructed, not of a rigid material, but of a plastic substance like that of our muscles. In any case, it is quite conceivable that

man might be able to construct an apparatus in which each part fulfilled a number of different functions.

In former discussions concerning the purposiveness of organic nature, one often heard the following argument: When we discover a tool, we conclude that it was made for some definite purpose. Analogously, from the purposive character of organic nature we must infer the existence of a creator (God, Entelechy). There is however a difference between the two cases. The purpose of the tool lies outside itself; the purpose of the organism is within the organism itself and consists in its preservation. There is no proof that the mutual adjustment of the parts of an organism is not determined by purely physical laws. And when the biologist replies to this that the blind forces and laws of physics are insufficient for biology, and that the forces in the organic world are purposive, we can answer by saying that to differentiate between these forces in such a way is absurd. The original concept of force included in itself the idea of purpose; but this anthropomorphic conception was abolished by the purifying influence of physics, because it was realized that nothing was explained thereby. Similarly, nothing is explained by the purposive forces which are supposed to govern organisms. The concept of a purposive force is either empty or anthropomorphic in content.

Neverthcless some scientists, like the vitalist Johannes Reinke, still retain this confused idea. Reinke thought that he had made progress when he introduced a life principle to take the place of the life force. His principle does not apply to atoms, but only to the most complex structures. New forces which are supposed to be distinguished from physical forces are in-

troduced. Reinke regards organization, reproduction and the psyche as the essential elements in the life principle; and he regards it as coordinate with the principle of energy. He attempts to base the autonomy of life on teleology; teleological forces which result in a special type of events—teleological instead of causal—are introduced. Reinke speaks of dominants, which are forces or laws that function purposively and to which causal events are subordinated. Every part of a body, every part of the eye, for example, but also the eye as a whole and finally the total organism, have their dominants. But this conception of a dominant law is not applicable to natural science. For it is only when natural laws are regarded as analogous to human commandments that the reciprocal relations of higher and lower, superior and subordinate can be applied to them. And once it is realized that the laws of nature are only general descriptions of the actual progress of events, this concept of dominants which are supposed to control all other forces, is undetermined. If vital forces really exist, they are not superior, but equal in rank, so to speak, to the physical.

Driesch also thinks that physical laws are insufficient to account for organic events. He attempts to prove the autonomy of life by a number of arguments, the most important of which maintains that the organism is not a machine. He demonstrates by experiments that if cells, which in one part of the organism develop into an eye, are transplanted to another part where normally an ear grows, they produce an ear and not an eye. Hence, the parts of an organism can be exchanged. Driesch calls a system of this kind a harmonious-potential system. Now, a machine can denote two

different things: on the one hand a system which obeys physical laws exclusively; and on the other one in which each part has a definite function. Driesch changes from one concept to the other without proving that the two definitions are identical. And the whole argument depends upon the identity of the two concepts.

Driesch's second proof is based on a special case of teleology in which the problem of sensitivity plays a part. A dead body reacts in a definite, unequivocal manner; an organism, on the other hand, can, under different conditions, react differently to external stimuli. Stimulus and reaction are not homogeneous in all their parts, but only as a whole. In inorganic nature, a similar stimulus always provokes a similar reaction; in organic nature, according to Driesch, it is otherwise. He illustrates this by a telegram, the text of which: "John passed a day at home" provokes a definite reaction which is independent of both the external form of the telegram and the phraseology in which it is expressed; while by an alteration of a single consonant ("passed away" instead of "passed a day") a totally new reaction is called forth. In cases like this, Driesch speaks of an "historical basis for the reaction of organisms". Against this, it may be said that such cases do not exclude the possibility of interpreting the reaction in both inorganic and organic domains in the same way. Even in the inorganic domain, quite a small difference in the stimulus can produce a totally different effect. One need only think of a very complicated mechanism in order to account for the dissimilarity of stimulus and reaction in the organism.

One of Driesch's ideas is correct—and it is an idea

central to the main issue. Driesch thought namely, that in all experiments to prove the autonomy of life, the chief point is that under quite similar conditions quite different things develop. Now, if nothing perceptible—that is, nothing which exists in space—is different, a new cause must be presumed, a cause which is distinguished from physical things by its non-spatiality. Everything physical must take place within a spatial system of co-ordinates. The presumed non-spatial cause is designated by Driesch as the intrinsic autonomy of life—or, in other words, *entelechy*. In order to prove the autonomy of life, it would have to be demonstrated that at different times, under the same conditions in the organism, different things happen. The proof of this is not, however, furnished by the example given above of the transplantation of a cell (eye-ear); because it is the different environment which determines the development. Thus it is a question here of spatial transactions; and hence we have no reason to assume the presence of non-spatial factors.

Whether we consider the phenomena of reproduction, inheritance, apparently spontaneous movement or any other data in the world of organisms, we find no problems which the individual sciences—biology and, indirectly, chemistry and physics—are not competent to solve. None of these problems gives rise to any difficulties of principle—epistemological difficulties—for the solution of which the help of philosophy is required. With regard to the problem of heredity, it has certainly been said that it is inconceivable how a complete individual with all its characteristics can be contained in such a minute object as a human spermatozoon. But this is not difficult to understand from the

epistemological standpoint—it is not at all marvelous, —for the relativity of all magnitudes teaches us that the smallest particle of matter can be just as differentiated—namely with an infinite multiplicity—as the human body. All the so-called enigmas concerning the phenomena of life are merely quantitative difficulties, as it were, and do not arise from the connections between domains which are inherently separated. Thus, for the philosophy of nature, organisms are nothing more than systems of peculiarly complex structure which are included in perfectly harmonious order in the physical world picture.

* * *

On the relation of quantum theory to biology, see Schlick's essay "Quantentheorie und Erkennbarkeit der Natur". ("Gesammelte Aufsätze" Wien 1938; re-published in "Gesetz, Kausalität und Wahrscheinlichkeit", Wien 1948).

APPENDIX

NECESSITY AND FORCE[23]

(Supplement to § 3)

IN EARLIER stages of the history of thought, when the content of natural concepts was represented in a more human form, a cause was looked upon as a kind of effort or striving, which was supposed to expel the effect out of itself, so to speak, by necessity. And causality was conceived of as a real link binding cause and effect together—a view which was combated by Hume in his day. At a later period, the mystic conception whereby the effect was supposed to be necessitated by the cause as through a kind of determination, was called by E. Mach a remainder of fetishism, and he consequently renounced the causal concept altogether for a "functional" dependence (in imitation of mathematical terminology). But this is really only an alternative nomenclature; it is difficult to understand why the real dependences in nature should not be designated as "causal", in contrast to the merely logico-conceptual ones of mathematics; especially as the concepts of cause and effect can be defined in a manner which is free of all fetishism.

Much more dangerous, in my opinion, is the anthropomorphism, or fetishism, which is so easily con-

nected with the term *natural law.* The word "law" is misleading, inasmuch as it is taken over from its use in connection with human society, and denotes a decree of Government which compels the governed to adopt a certain type of behaviour. But a law of nature is in no sense a decree transferred to nature which exerts compulsion, so to speak, on things, and demands obedience from them. Natural law is a simple formula which *de*scribes the actual behaviour of nature and does not *pre*scribe what it should be.

The concept of causality, and consequently that of natural law includes the concept of necessity. But what is the true meaning of the latter expression? It no longer means a kind of *compulsion* (which would be the opposite of "freedom", and which presumes the effort, or striving, of a conscious being), but instead a type of *regularity* (which is the opposite of "chance" or absence of law). Here, necessity means nothing more nor less than universal validity; the sentence: "A follows necessarily from B", so far as content is concerned, is completely identical with the sentence: "*In every case* where the state A occurs, the state B follows", and says nothing more whatsoever. It can be seen from this that in nature, there can only be a question of causality, law or necessity when, in some sense, a repetition of the same thing occurs. Only when the same (or at least, similar) processes are possible in different places and at different times, is there any meaning in the statement that A follows *every time* from B. The idea that the homogeneity of nature is a necessary condition for the existence of the concept of law, should not be surprising—inasmuch as all knowledge and consequently the formulation of natural laws also, is

based on the discovery of similarities (identities) in the world.

Similar errors to those engendered by the concepts of cause and necessity, have often arisen as the result of another concept which is sometimes even compared with the concept of cause—namely, that of "force". Even to-day, forces are sometimes believed to be the real causes of natural events; and involuntarily, something akin to will, which strives and is directed to an aim or goal, is imagined thereby. When it is observed that a stone, when released, falls to the earth with a definite acceleration, this is ascribed to the "force of gravity" of the earth which "seeks" to draw the stone to it. G. Kirchhoff and E. Mach especially, pointed out quite rightly that such anthropomorphic conceptions as these, however easily they may be explained as due to the origin of the concept of force, have nothing to do with physics. The concept of force undoubtedly owes its origin to the muscular effort which human beings experienced when they attempted to set bodies in motion. They observed that the muscular effort necessary in order to move a body is greater the more it is desired to accelerate the motion—and, in addition, depends on a factor which is determined by the nature of the body and which was known as "mass". Thus, mass multiplied by acceleration was *defined* as the measure of force. (It was Newton who was responsible for this).

If we establish that an electrically charged particle of known mass, for example, suffers a certain acceleration at a given point in an electrical field, we can say—in accordance with the definition—that a force which is equal to the product of its mass and acceleration, is acting on the experimental particle at that

point. But, obviously, we must not imagine that some sort of "striving or effort" which, with great expenditure of exertion, is attempting either to push the particle away or to draw it near, is residing at that point in the field. The only assertion that we can make is that, at that point, some state prevails, or some processes are taking place, which may be considered to be the causes of the acceleration. If we wished to identify "force" with this cause, it would merely be a name for the field processes themselves; but the terminology would be extremely inappropriate. If we do not interpret the word "force" as meaning a process, but use it to designate a certain *regularity* in the process, this coincides much more closely with the meaning of the structure of physical concepts. We shall proceed to make this point clear at once.

It was sometimes thought that force *is* nothing more than a mere arbitrary measure of motion, that it is identical with the product of mass multiplied by acceleration and means nothing more than this. But such an idea cannot very well be maintained. Force is not a mere measure, but is *itself* measured by the aforementioned product. Force (in our example) is not imagined as something in the motion of the body itself, but as something in both the cause of this motion and in the field processes on which the motion depends. This follows, for example, from the fact that contemporary mechanics (of Einstein) no longer regards the equation: Force = mass × acceleration as universally true, but only ascribes approximate validity to it in the case of very small velocities. And this would not be possible if it were a question of a completely *arbitrary* definition. In reality, we are supported in

this contention by quite definite empirical data, such as the following (ideally represented): If two particles of different mass and velocity be subjected, one after the other, to the same external conditions—at the same point in an electrical field, for instance,—they will behave quite differently. But since by "force" we understand something akin to the state of field, we may say: Both particles at that point are acted upon by the same force (whereby it is assumed that the presence of these particles does not perceptibly modify the state of the field). Thus, in order to find a measure of the force, we must observe which quantity remains the same throughout the varied behaviour of the two bodies. We then discover that a quantity of this kind as a first approximation, is the product of mass multiplied by acceleration; and the justification for the measurement of force by this quantity, in the older mechanics, consists *in this alone*. (We ignore for the moment, various difficulties which present themselves in the definition of the concept of *mass*). And in the new mechanics, this product is replaced by a more complicated expression, inasmuch as it was realized that the new expression represents the simplest quantity which has the same value in both cases.—Anyone to whom this example of electrical force is unfamiliar, must imagine the two particles as brought in contact with a spring which is being released from tension and which is in the same state on both occasions. We can then say that in both cases, the same force (that of the spring) acts on both bodies, and once more search for the quantity which has the same value on both occasions. We have then discovered the measure of the force. But the equality of a unit of measurement or scalar quantity

like this, is the expression of a regularity—and of a regularity of those processes in the spring (or in the electrical field of our first example) which we may regard as the cause of the observed acceleration of the experimental body on which the force "acts". Accordingly, we maintain that we must not regard the "forces" as in any sense causes, but as the expression, nevertheless, of a regularity of the causal process.

Our interpretation of the concept of force was made on the basis of the empirical fact that "forces which act at a distance" do not exist, and that existence can only be ascribed to actions which are propagated continuously from place to place or from point to point. For the analysis of the concept of force, we need only take into account the immediate neighbourhood of the particle on which the force is acting; and can ignore the dependence of its prevailing states on a more distant neighbourhood. It would be quite a different matter if actions at a distance were suddenly to occur in nature. In that case, in order to define the concept of force, we should have to refer to the total constellation of all the bodies concerned; and force would have to be conceived of as the description of the regularity of their total behaviour. The difficulty of this conception certainly contributed to the aversion already entertained, at an early date, by scientists towards the hypothesis of action at a distance which they declared on a priori grounds to be impossible. In their rejection of this hypothesis, they referred to such sentences as: "A body cannot act where it is not". As against this, it must be definitely stated that the impossibility of action at a distance cannot be proved philosophically. Only experience seems to teach us that

such a thing does not exist and that it is more practicable to describe the connections of natural events on the assumption that these occurrences, at every point, are solely dependent on others in their spatio-temporal neighbourhood.

THE CONCEPT OF THE ATOM[21]
(*Supplement to* § 5)

1. *The Mechanical Theory of the Atom*

THE CONSTANT, or invariant, which was thought to be the basis of all changes in nature—the self-identical vehicle of the variable characteristics of all bodies which are accessible to sense-perception, was known as Substance. Now, what was this self-identical entity; and what concepts were necessary in order to designate it? Every closer designation was again merely a statement of attributes. Hence, if it is desired that substance should *not* be something which is incapable of intuitive representation and incapable of further specification and that it should *not* remain a mere postulate,—the last halting point of knowledge,—but should be a real means of explaining something, then it is essential to specify its fundamental properties. For obviously, something of which no properties are known, cannot be of any use in explanation. Moreover, these properties, or attributes, had to be invariable, constant and self-identical,—inasmuch as their function was to express the nature of Substance. Thus, the method and possibilities of an explanation of nature were both clearly manifested.

The variable properties of visible substance had to be conceived of, both as originating in *those* processes in a primary substratum which leave its essential attributes unchanged, and as being reducible to this substratum. And *motion* seemed to be the process which fulfilled these requirements. But which were the fundamental characteristics, or qualities of the substratum set in motion, which could be regarded as invariable? They could not be the sensory qualities of tangible bodies because these are subject to change. Warm, flowing water becomes cold and hard when frozen; the colour, smell and taste of things change under varying conditions of perception. What then remains unalterable? The Greek philosophers, Leucippus and Democritus, after being forced to renounce all "subjective" sensory qualities like red, hot, sweet etc., were obliged to regard "filling or occupation of space" as the only quality left to matter. And in fact, this quality seemed to be a necessary residual (since, at that stage in the history of thought, only something pictorial came into consideration); and it also seemed to be adequate to account, in a pictorial form, for the behaviour of the different substances.

This came to pass with the help of the *atomic theory* which consists in the assumption that substances or bodies in extension, are not in reality continuous spaces completely filled by substance, but are composed of very small parts which cannot be further subdivided. The essential nature of the latter, consists in "occupation of space". According to this definition, two bodies cannot both occupy the same space at the same time—unless they are identical. In other words Substance is *impermeable*. Between these small spaces

which are completely filled with matter—the atoms—there are empty interstices of space which may be regarded as comparatively large, light and porous bodies; whereas the atoms are packed tightly together in compact and heavy bodies. The individual atoms are not, of course, qualitatively differentiated from one another, since the essence of Substance—the filling or occupation of space—is the same for all of them. The only possible difference between them consists in the size and shape of the space they occupy; and in their position and motion. Democritus thought that atoms possessed depressions and elevations, as well as hooks and loops, so that they were more or less firmly interlocked and, grouped in formations, exhibited the characteristics of either fluid or gaseous, harder or softer, bodies—despite the fact that the atoms of the structure all continued to be absolutely hard and invariable in shape.

At the same time, this theory of the atom had one advantage, from the standpoint of epistemology, which cannot be too highly estimated: it yielded a world picture devoid of all qualitative differences. All the qualitative differences in nature were replaced by those of size, form and motion—in other words, by numerical, by conceivable or quantitative determinations. This is, of course the essential condition for every *mathematical* formulation of natural knowledge; and hence for those methods which have raised physics to the highest rank amongst the sciences of reality. Thus, the atomic theory of antiquity had a very high aim which, with the simple means at its disposal it could not possibly attain.

When the atomic theory, which had been as good

as forgotten during the Middle Ages, was introduced into science in modern times by Dalton, it made its first appearance in a more modest form and did not claim to derive *all* properties of substances from the assumption that *all* atoms are qualitatively similar—in other words, that they are derived from the atoms of only *one* substance; but was for the time being satisfied with as many different substances as there were "chemical elements"—at that time, a fairly large number. On the other hand, the new theory had an enormous advantage over the old, in that with the help of its hypothesis, it could explain quantitatively a great number of chemical facts. Briefly, it could refer to empirical facts to support and prove the truth of atomism.

But more important for philosophical development than this conception of substance, was the subsequent application of the atomic theory to special *physical* problems, first in the so-called mechanical theory of matter, and particularly in the "kinetic theory of gases". The regular behaviour of gases, which is simpler than that of any other substances, could be deduced both numerically and with great accuracy, from the hypothesis that a gas consists of the smallest particles, each of which moves freely in accordance with the laws of mechanics, and in obedience to the law of inertia, describes a rectilinear path in space until it collides either with the sides of the vessel or with another particle. This theory which afforded a plausible interpretation of the nature of heat, was a sign of considerable progress. The temperature of a gas (and, more generally, of every substance) is, according to this interpretation, nothing more nor less than the average "living

force" (or "kinetic energy") of these particles.

In order to complete the theory, it was necessary to ascribe to the particles (the atoms or molecules) a new property, namely that of perfect elasticity; which means that in the reciprocal impact of the particles with the sides of the vessel, there must not be the slightest loss of kinetic energy—a corpuscle must, for example, rebound from the side with a velocity exactly equal to that with which it collided with the vessel. But the idea of such a mechanism naturally involves difficulties.

The fact that we have no experience of perfectly elastic bodies does not matter—in the atomic theory, their existence must be assumed hypothetically. But how is the process of impact to be imagined? Elasticity only exists in bodies or substances which can be deformed or distorted. Two billiard balls at the moment of their impact, become slightly flattened, but recover, at once, their original shape again; and it is through this very recovery that they are forced apart. If one were to assume, in the case of atoms in collision, that when their surfaces come into contact with one another at one point, they separate again immediately without any change of shape, this discontinuous process of an infinitely rapid reversal of velocity, would denote a breach of the laws of mechanics. But if, on the other hand, one were to agree to the compression, then the original concept of substance would have been abandoned. For if the *same* substance, in a state of deformation, can fill a smaller space than before, then its essential nature is no longer characterized by the designation: "occupied space". For the *degree of compactness or density,* with which the substance occupies space

would have to be additionally stated.

And this would introduce a new qualitative definition of Substance which would contribute nothing to an explanation of elasticity. For in tangible bodies, the compressibility, as well as the different degree of density, could be explained by a diminution of the intervals, or interstices, between the completely rigid atoms. But in the case of atoms themselves, this is not possible, because they are compact and do not possess pores. It is easy to see that in attempting to perfect the atomic theory, the question of the inner structure of the the atom cannot be avoided. And this problem always leads to contradictions in respect of Substance when regarded as mere occupation of space. Of course it is true that the concept would in any case have been abandoned if in chemistry, the substances of the chemical elements had really been regarded as irreducibly different in quality; but this view was doubtless only held temporarily, and the conviction that as knowledge progressed, these properties or characteristics would be further reduced in number, was never renounced. In which case, as soon as mechanical explanations were sought, the contradictions would become important.

These difficulties were already inherent in the atomic theory of antiquity. If an atom, as envisaged by Democritus, for example, were supplied with a hook, we should be justified in inquiring: why cannot the hook break off? We can *imagine* the hook as broken off, and ask: what holds the hook and the rest of the atom together? Why is it that structures which are conceptually divisible, are physically indivisible? The atom of Democritus behaves as though all its parts

were linked or joined together by infinite forces. And even if it were permissible to speak of such forces at all, they would introduce a foreign element into the original concept of substance which would invalidate it. We are thus involved in difficulties everywhere; and can only avoid them by pursuing a new line of thought and abandoning the old. One of the two ideas—the atomic theory or the concept of substance—which in their hitherto existing forms are incompatible, must be renounced. We will next consider the second possibility, or the attempt to arrive at a more satisfactory conception of the constitution of matter by abandoning the concept whereby Substance is mere "occupation of space".

2. *The Dynamic Theory of the Atom*

The idea of atoms as rigid, space-filling structures was, as we have just seen, confronted with difficulties as soon as the attempt was made to depict the process of impact in conformity with the fundamental hypothesis, and with mechanical laws. The forces necessary to drive atoms apart after collision, could not be deduced from the concept of Substance as mere occupation of space, or from impermeability. These difficulties could, however, be avoided and the process be regarded as continuous, if it were first assumed that between the atoms, there exist forces of repulsion which become more powerful the smaller the space-intervals between the atoms. (The theory suggested by the empirical data of universal gravitation—namely that the atoms mutually *attract* one another—does not necessarily contradict this hypothesis which need only be

true for greater distances; in the case of lesser distances, the attracting forces could be transformed into those of repulsion). Where two atoms approach each other, such forces would cause an increasing diminution of their velocity until a state of rest was reached, after which a reversal of the motion—which would occur before the corpuscles came into contact with each other —would take place. This would be a completely continuous process in total agreement with mechanical laws, which is made possible by the introduction of an entirely new agent in the shape of atomic *forces*.

Thus, the concept of Substance was extended, inasmuch as forces were added, as something distinctive to mere occupation of space. But if we ask what rôle is now played by "occupation of space", which was originally the essence of Substance, the answer is: none! It has ceased to appear in any part of the mechanism. The size and shape of the smallest particles are quite immaterial; they may be as large or as small as desired (provided that their size remains below a certain limit) and the course of the processes would not be in the very least altered. There is never any question of contact with the surface of an atom; hence, its form and extension do not exert any influence. All that must be taken into consideration in the scientific explanation of the atom, are the forces which emanate from it. The space-filling-or-occupying mass, or body, of the atom is no longer used in any kind of explanation—it serves at the most as the vehicle, or centre, of forces. And in this guise, it need not be extended at all; so that the hypothesis of space-filling Substance is superfluous. And from this it follows that the concept of Substance is completely changed in meaning. For the only right

and honest course is to refrain from asserting the existence of a quality for which no place in the theory can be found, and which, in consequence, cannot be tested or proved. If atoms be really left to function solely as centres of forces, then this function *only*, should be included in the concept of Substance; and space-occupation should not be dragged along as superfluous ballast.

And so we have arrived at the point where matter is conceived of as consisting of point-centres—the so-called Boscovitsch atoms—between which certain forces act; or rather, it consists of centres, the essential nature of which consists exclusively of the action of these forces. Accordingly, substance itself is no longer extended; and the extension of bodies is solely due to the fact that the point-atoms of which they consist, are kept apart by the forces of repulsion. This is the "dynamic theory of matter", in which the essential nature of substance is regarded as consisting of forces to which extension is reduced; whereas the older theory of Democritus, on the contrary, sought to deduce the forces acting between particles from extension—and failed in the attempt.

The dynamic theory, by virtue of the simplicity of its fundamental concepts, is an impressive structure which had a very strong attraction for philosophic minds. Kant was an adherent of it; and Helmholtz, in early life, was completely under the spell of the idea of forces as represented in the dynamic theory—he even held it to be the necessary and only possible means of explaining nature. At that time, he maintained that: "The task of the physical sciences is to reduce natural phenomena to constant forces of attrac-

tion and repulsion, the intensity of which is dependent on the distance". And he added: "The possibility of fulfilling this task is, at the same time, the condition of the intelligibility of nature". He believed, of course, that he could, by abstraction at least, separate the concept of Substance-in-itself from its forces: "Thus the essential nature of matter-in-itself is for us a state of rest, of inactivity. . .". Helmholtz expresses very clearly the fundamental idea which is so important for the purely mechanical theory of matter—namely, that of the elimination of all qualitative differences in substance. "We may not ascribe qualitative differences to matter-in-itself: for when we speak of different kinds of matter, we are only thinking of their different effects—that is, of their forces. Thus, matter-in-itself can undergo no other than a spatial change—which is motion".

The logical development of the idea of atomism was responsible for the overthrow of the concept of Substance as something spatially extended; and the mechanical conception of nature attained thereby the peak of this line of thought. An image of nature of great simplicity was thus unfolded; and even though contemporary science has long since abandoned this world picture as being a conceptual structure which is quite inadequate to represent reality, this is not because of internal disagreement between the ideas developed, but is simply due to the failure of the dynamic theory to explain certain empirical data: no satisfactory system of physics could be built up from its hypotheses.

3. *The Theory of Continuity (Vortex Atoms)*

In the dynamic theory which we just have de-

scribed, the idea of substance as something which fills or occupies space, was overthrown by atomism. Nevertheless, it seemed as though it might be possible to evolve a theory of matter by the opposed method—namely, by maintaining the identification of Substance with occupied space, and renouncing atomic structure for a theory of continuity.

If the fundamental idea of the atom of Democritus—namely, the indivisibility of its substance—be abandoned, then rigid atoms, as bodies of a definite shape, no longer exist. Every quantum of substance can be decomposed as often and at as many points as desired; and its particles can with infinite ease be reciprocally displaced. In a word, their behaviour is similar to that of a *fluid,* with highly idealized properties, which would have to be described as an ideal fluid.

Now it is possible on the basis of such a concept of Substance to draw a connected, explanatory picture of nature. At first sight, this would appear to be impossible; since it seems inconceivable that an iron rod, for example, could in reality be imagined as constructed from fluid substance. But a closer examination of the properties of fluids, reveals the existence of hitherto unsuspected possibilities. Everyone is familiar with the rings of tobacco smoke which clever smokers create for their own amusement. These are structures in which the air and the smoke particles together, whirl with some velocity round an annular axis. Now, vortex rings of this kind are possible in every fluid; and Helmholtz discovered the exact laws which govern their motions by solving the equations which Euler had formulated for the behaviour of such fluids. He found that in an ideal, frictionless fluid, rings of this

kind can neither be destroyed nor created: once they exist, they continue to do so to all eternity. They can move in manifold directions, change their shape and mutually influence one another—but no ring in an ideal fluid can either disappear or be created anew. This quality of indestructibility was actually the chief characteristic of the atom of Democritus; and the fact suggested an inquiry as to whether such vortex rings could not be regarded as the building stones of matter. The hardness and solidity of substances could easily be explained by assuming that the particles of an invisible, minute "vortex atom" whirl round with very high velocities. In which case, a structure of this kind (like an extremely rapidly revolving top) possesses the capacity to resist with great force, all external influences, and to behave as though it were both hard and rigid. Hence, by virtue of its dynamic behaviour, it can easily create the mistaken impression that it actually possesses these properties.

Lord Kelvin was the originator of the idea of vortex atoms. He and J. J. Thomson subsequently pursued this theory further; and Helmholtz was also attracted by it. The world picture of the vortex theory of the atom—which is really a theory of continuity—was as follows: Empty space does not exist; space is completely and continuously filled with an absolutely frictionless, incompressible fluid (the aether of space) in which innumerable annular motions of the kind described, take place. These annular vortices may be quantitatively different from one another; and all substances or bodies accessible to sense-perception originated from them. In view of their indestructibility, they may well be called "atoms"; but they have the advantage over the

atoms of Democritus, in that their indivisibility is no longer an ultimate, inexplicable property, but seems to be derivable from the very nature or essence of Substance. And here, this essence consists solely in occupation of space together with the capacity to move in accordance with Newtonian mechanics—that is, in accordance with Euler's formula. Thus, in this theory, the original concept of substance appears to be maintained.

The objection raised by some philosophers to this idea of substance—namely that if empty space did not exist, there could be no motion; and that the idea of a continuous, arbitrarily divisible substance would involve the contradiction of a completed infinite divisibility—are quite untenable. For if these ideas were contradictory in themselves—intrinsically contradictory—they could not be so perfectly represented in mathematical form as they are in Euler's equations.

On the other hand, the discussion of another objection to the theory of the continuity of substance which was made, and subsequently often repeated by Leibniz is interesting from the standpoint of philosophy. Leibniz argued that although whenever any motions take place in matter which is everywhere perfectly homogeneous and continuous, the particles of substance change their positions, yet whenever a particle moves out of its position, another immediately takes its place. Accordingly since this other is qualitatively the same as the first, the state of the whole remains exactly as before:—they are both completely indistinguishable, and all is as though nothing had happened. Moreover, this is equally true of all possible states—each is completely similar to the other. So that under all conditions, sub-

stance of the same nature exists at every point and at every instant. Hence, in such a world, there would be no change and consequently no events; and it is therefore absurd to attempt to explain nature which is infinitely various and in a state of perpetual change, by means of such ideas.

This objection would be sound and would certainly invalidate the theory of vortex atoms, if mere *existence* of matter played some kind of explanatory part in the theory. But this is not, in any sense, the case. Instead, the only explanatory principle applied in the world view described above, is that of the *motion* of matter which moves at every point with a certain velocity, which has both a definite magnitude and a definite direction. It is true that exactly the same substances are to be found at every point in space at any instant of time; but this is no reason why the states of the Universe at different times, should be the same and indistinguishable. For substance is continuously changing its *state*—namely, its state of motion. And according *to this theory, matter in motion is different from matter at rest.* So that when Leibniz, in his argument, abstracts from motion, he is leaving out just what constitutes the nucleus of the theory. The theory ascribes to every point of general space, whether inside or outside a vortex, a definite velocity depending on magnitude and direction; and all the motions of vortex atoms and of the substance lying between them, are expressed by stating the way in which the velocity at every point in the space changes. Since magnitudes which, in addition to a numerical value, possess direction, are called "vectors", we can say that the theory of vortex atoms denotes the attempt, with the help of a single type of

vector—namely, that of velocity—to give a complete description of all natural events. Nature appears as a gigantic "vector field". It is, of course, quite immaterial for the conceptual content of the theory, that this vector which describes the state of nature at every space-time point, is interpreted as just the velocity of motion of a *substance*. In other words, the concept of substance is here reduced to motions,—just as in the dynamic theory it was reduced to forces. Here, "occupation of space" plays a fundamentally different rôle from that which was originally assigned to it.

But the theory of vortex atoms, by virtue of the simplicity of its principle, represents a truly great enterprise which, had it been successful, would, to a very large extent, have satisfied the human desire for knowledge; the infinite variety of nature would have been reduced to a simple basic concept which would have surpassed the boldest desires of Thales when he uttered the phrase: "All is water". And at the same time, the mechanical conception of nature would have celebrated a great triumph—inasmuch as all events in the world would have been interpreted as motion.

But to-day, the theory of the vortex atom can no longer be regarded as a physical theory. The vortex rings or combinations of such, do not possess the properties which they must have in order to explain accurately and numerically, the observed processes of nature. No empirical data—such as those of chemistry or electrical theory—could be satisfactorily classified in the world picture of this theory. And thus no scientific value can be ascribed, either to this interesting attempt, or to later versions of the same fundamental idea. This is true to-day of all mechanical theories,

inasmuch as contemporary physics has, for fundamental reasons (which will be mentioned later) renounced the idea of reducing all natural laws to laws of motion—in other words, of reducing all natural events to mechanics.

4. *Energetics*

The attempts to base a world picture on ideas of Substance which are philosophically satisfying, resulted in those mechanical theories described above, which did not fulfil the hopes placed in them because, as scientific hypotheses, they proved to be impracticable. Hence it was a natural consequence that all fundamental hypotheses of the kind should be regarded with distrust; and even that the attempt should be made to prove their inadequacy from the epistemological standpoint. A description of nature devoid of all hypotheses was now considered and thought to be feasible by the rejection of all propositions concerned with entities—like the atoms—which lie outside perception, and by the formulation of natural laws which contain exclusively, propositions concerned with magnitudes or quantities that are directly measurable and hence actually existent in nature. Thus, it was no longer permissible to search for the epistemological relations between the different physical domains—of mechanics, heat and electrical theory—in some ultra-microscopic atomic mechanisms. Another bridge to link them had to be discovered; and both the concept of *energy* and the law of the conservation of energy seemed to offer themselves for that purpose.

The energy of a physical system (referred to a definite initial state) represents, as we know, the

amount of mechanical work which can be obtained from the system (if it be transferred to that initial state). This quantity is quite determined, and is independent of the intermediary states through which the system may pass in the process of transference. And exactly the same amount of work must be supplied to the system in order to transfer it from the normal, initial state to the final state from which the start was made. From this it follows that no physical system exists from which work in indefinite quantities can be obtained without compensation. A "perpetuum mobile", or machine which can produce work from nothing, is an impossibility; and it is thus an empirical fact that work can neither originate from nothing, nor disappear into nothing; but that wherever it is gained or lost, a corresponding quantum of capacity for work either disappears or is created anew in another form,—as electrical, chemical or any other existent form of "energy". Hence, within a system which is isolated from the surrounding world, the sum of all energies is constant and represents a quantity which is invariable throughout all transformations.

Obviously, the idea of this energy as the true "Substance" which is the invariable basis of all natural processes, was bound to suggest itself; and in this way, the "energetic" world picture came into being—a picture that was specially developed by Rankine and Ostwald. Ostwald's view was that nothing exists except this energy which is continuously self-identical, but manifested in various forms—that is, it can assume qualitatively various properties or characteristics. Moreover, all events in the world consist solely in the transference from one form to another of this energy which, al-

though its properties change in obedience to rules which are the content of natural laws, always remains essentially the same. Heat is not identified with motion here, as it is in the atomic theory, but is conceived as only something qualitatively different which can be transformed into motion in accordance with strict laws.

To-day, this world picture which, as an idea, is not without genius, has no longer any adherents. The disadvantages or errors which make it unacceptable to modern research are the following:

1. The claim, which it makes, to be quite devoid of hypotheses, is not justified. For in order to be able to explain all natural phenomena, assumptions concerning the essential nature and behaviour of energies —which are just as much hypotheses as the assumptions concerning the essential nature and behaviour of atoms —must be made. For it is certain that energies can neither be observed nor measured at every instant of time or at every point in space.

2, The different forms of energy (heat, gravitational energy, energy of volume etc.) are introduced as ultimate properties which cannot be further apprehended. They are no longer reducible to one another; and the theory declines all explanation of why energy manifests itself in those particular forms with their special properties, or characteristics. Our craving for knowledge can never be satisfied with such an idea; it urgently demands a continuously increasing unification of nature—especially in view of the fact that physics has already most successfully achieved such a unification in the explanation of heat as a form of mechanical energy, and light as a form of electro-magnetic energy, for example. The conception of nature accord-

ing to energetics, would cause physics to fall back to a stage of its development which has been successfully overcome; instead of being a unified science, it would become disintegrated into as many irreducible, component parts as there are different forms of energy. And such a classification would betray its derivation from the varieties of sense-perception. Formerly, optics (the theory of phenomena accessible to the visual sense), acoustics (corresponding to the auditory sense), mechanics (tactual and motor senses), theory of heat (temperature sense) and electro-magnetism (which is not co-ordinated to any particular sense, and hence is the latest to be developed) were all differentiated in this way. Now, it is precisely the task of physics to describe nature in a way that is, as far as possible, independent of subjective ideas which are entirely conditioned by the chance organization of the human being—namely, by the number and kinds of senses through which he perceives the external world. And as a matter of fact, modern physics has long since rejected this old multiplex classification, and now distinguishes only mechanics and electro-dynamics. For, in spite of many attempts, the unification of the two latter has not yet been completely accomplished. Obviously, what we have been saying, does not deny the fact that in text books of experimental physics, the old classification has been very largely retained. For these books are not concerned with the system of physics, but with showing the way to that system. Hence, their description must start out from perception and is, moreover, influenced by didactical considerations.

3. Finally—and this is especially important from the standpoint of the philosophy of nature—in view

of the fact that energy in it fills the rôle of Substance, according to the old interpretation, Energetics is faced with a significant reconstruction of the concept of Substance that is required by the principle of energy itself. The principle of the conservation of energy, when examined more closely, only states that certain, different measurements, under conditions which are definitely determined, always produce the same result.

The principle thus merely asserts the numerical constancy or invariance of a sum of certain quantities (those of the "energies"); and when Energetics interprets this statement as though it were a question of the quantitative invariance of a self-identical substance, a metaphysical interpretation is implied which exceeds the mere content of the physical principle. We shall soon see that physics has weighty reasons for renouncing, to an increasing extent, the idea of identity and for retaining instead, that of constancy or invariance; in this way the old idea of substance would be abandoned and reduced to that of law. This denotes a substantial progress in knowledge; and Energetics which, because of its specific interpretation of the principle of energy, is favorable to the retention of the old concept, would signify a reactionary tendency.

Each of the three reasons enumerated above, is in itself sufficient to prove the impracticability of this theory as an ultimate interpretation of nature.

5. *The Electrical Theory of the Atom*

During the last few decades, a new physical world picture has arisen and won a victory over all others. In this theory, neither a mechanical explanation of all

natural phenomena is attempted, nor, like Energetics, does it strive to reduce the various domains of physics to one another. Instead it achieves by means of a small number of daring hypotheses a unification of the conception of nature which, if developed consistently, could satisfy to some degree the aspirations of both the physicist and the philosopher of nature.

The fundamental concepts upon which the new theory is based, are taken over from the theory of electricity; and with the help of the latter, atomic theory receives new content. The atomic structure of matter is confirmed to such a degree, by chemical and other data that, in one form or another, the atomic theory has become indispensable in every physical world picture. Nevertheless, it need not necessarily be the ultimate explanatory principle, as it was in the conceptions of both Democritus and Boscovitsch; it may quite easily be derivative and be compatible with the hypothesis that ultimate reality has not an atomic but a continuous structure. We have already become acquainted with an example of the latter possibility in the hypothesis of the vortex atom.

The incentive to this new theory was given by the introduction of atomism into the theory of electricity. Innumerable empirical data confirmed with increasing certainty the hypothesis that electricity also consists of minute, indivisible particles; and it could be very successfully proved that the atom of matter—i.e. of the chemical elements—is composed entirely of such particles of electricity. According to this hypothesis, every chemical atom consists of a positively charged "nucleus", and a number of negative particles of electricity —the so-called "electrons"—which rotate round the nuc-

leus with great velocities. The electrons are all alike—that is to say, that each electron represents the same minute quantity of negative electricity. The number of the positive elementary charges of the nucleus is equal to the number of the electrons which (in the normal state of the atom) rotate around it. Thus, the whole atom is positively and negatively charged to an equal degree—and hence, gives the appearance of being electrically neutral. The chemical elements are distinguished from one another solely by the number of positive charges in the nucleus. The atom of hydrogen whose nucleus has a single charge and is accompanied by *one corresponding electron*, is the *simplest*. The nucleus of the helium atom has two charges and is accompanied by two electrons—and so on, throughout the whole series of the chemical elements, up to uranium whose atom possesses a host of electrons—not less than 92—and the corresponding positive charge.

It is not necessary here to go into the details of this theory, but is sufficient to emphasize that with its help, such a prodigious number of physical and chemical data have been explained and, in part, predicted, that the conceptual content of the theory must have a very high truth value. Incidentally, it also provides us with a great deal of certain scientific knowledge; but here, we are exclusively interested in its philosophical significance.

At first it would appear as though this theory must indicate a great triumph for the concept of *Substance* which is now known as electricity. It seems as though the character of Substance belongs more justifiably to electricity than to either of its predecessors, mass and energy. We know to-day quite definitely that mass—

that quantity (usually measured by its "weight"), which plays the part of Substance in all mechanical world pictures—is not an invariant; and that although the "law of conservation of mass",—which was formerly regarded as fundamental—is usually approximately correct, it is not exact. The Theory of Relativity especially, teaches us that the mass of a body depends on its velocity and increases enormously when the latter approaches that of light. Thus, in view of the present state of our scientific knowledge, mass can no longer be regarded as Substance in the old sense.—Moreover, as far as the energy of which we have spoken is concerned, there are two reasons for maintaining that it has a lesser claim to "substantiality" than electricity. In the first place, the constant amount of energy of any closed system varies according to the state of motion of this system in relation to that from which the amount is measured. It is not, of course, necessary to accept this disadvantage as decisive. Secondly, the most recent experiments in the domain of quantum theory, give rise to grave doubts concerning the absolute validity of the principle of energy. Indeed, it seems hardly possible to avoid the supposition that energy is constant only on the average, and that the principle of energy is not invariably true in the case of the very fine processes taking place within the atom; but that energy in small quantities can even completely disappear and re-appear once more—whereby, it must be noted, the losses and gains eventually neutralize each other.

Doubts of this kind do not occur in connection with quantities of electricity. According to our present knowledge, positive and negative charges can neither appear nor disappear[25]; nor is their quantity depen-

dent on the situation or motion of the observer. In fact, their constancy, or invariance, seems to be unqualified—and that is why the elementary particles of *electricity were really believed to* represent the true substance of nature. I will now quote the words of a great physicist, Arnold Sommerfeld, which are taken from his book "Atombau und Spektrallinien"[26]: "It is certainly true, that to-day, we regard electricity as something substantial. It is the only universal, basic substance which is equal in rank to that other basic substance known as positively charged matter.... As opposed to the mass, the charge proves by its constancy that it is true substance". And in a modern text-book of physics[27] we find the following statement to the effect that: "Modern physics may justifiably consider electricity to be the true primary substance from which all things accessible to sense-perception are derived and which has been sought by investigators of nature for thousands of years".

When it was discovered that a quantum of electricity—such as an electron—when in motion, behaves as though it possessed mechanical mass (since, according to the principles of electrical theory, it resists in a characteristic manner every acceleration—that is, it exhibits a property of inertia exactly like the inertial, mechanical mass), an "apparent" mass of electricity was spoken of; and the possibility now presented itself of declaring all mechanical masses to be "apparent"—that is, of reducing them to electrical masses. In this way, an "electro-dynamical theory of matter", was evolved, which was regarded as the successor of the old mechanical theories; and the idea was prevalent that

in this way mechanics was reduced to electrical theory.

It must, however, be noted that the expression "electrical theory of matter" was a little previous, inasmuch as it appeared very questionable whether the mass of the nucleus, for instance (which is bound to the positive particle of electricity and which is roughly 1800 times greater than the mass of the electron), can be regarded as purely electrical. For although this seems, in principle, to be quite possible, the facts are usually formulated in such a way that it is said (see the above quotation from Sommerfeld) that positive electricity is only manifested in combination with "ordinary" matter—that is, with a mass of which the electrical nature cannot be regarded as proved.—Secondly, it is doubtful whether it is the total mass of the electron by itself which may be explained as being purely electrical in nature; or whether, perhaps, a localized "energy of cohesion" within it must not be regarded as a contributory factor (namely, certain forces of cohesion have been sometimes introduced to explain why the negative charge after repulsion is not explosively split asunder, but remains concentrated within the electron).—Finally, and most important of all, the fundamental property of matter—namely reciprocal attraction, or gravitation—remained as an irreducible residue of Newtonian mechanics. Thus, the mechanical and electro-dynamical basic concepts were still disunited in this world picture. All other domains of the physical world appeared—as we have just said—to be finally reduced to mechanics and electrical theory. But the final unification of these two phases of the physical system appears not to be achieved by the assimilation of mechanics by electro-dynamics, but by the absorption of

both in an inclusive system in which they are combined in a higher unity.

In contrast to mechanical theory, electro-atomism is concerned with basic concepts which are totally non-perceptual,—inasmuch as the "essence" of both electricity and electrical and magnetic forces cannot be perceptually represented. It is true, of course, that a certain extension is ascribed to electrons and atomic nuclei which can even be numerically estimated; but it is not thereby asserted that an electron is to be conceived as a specific, electrically charged volume in the sense in which the atom of Democritus was imagined to be an impermeable substance-filled space; on the contrary, the numerical estimate of the diameter of such a particle is only to be conceived as the average distance representing the limit to which the supposed centres of the particles can approach one another. And—as in the dynamic theory of the atoms of Boscovitsch—this fact must be regarded as the expression of definite regularities in events, and not as signs of the existence of an "impermeable Substance" or something else of the kind. A particle of electricity cannot be regarded as something clearly and sharply separated from the environment: outside and inside are difficult to distinguish here; and the particle, presumably, merges gradually with its environment.

This environment is the "electro-magnetic field", a vacuum filled with electrical and magnetic forces; and these we must think of as "vectors" of a totally non-pictorial nature. But in this theory, the electro-magnetic field plays as important a part as does the behaviour of the electrons which are imbedded in it.

THE TEMPORAL EVOLUTION OF THE UNIVERSE[28]
(*Supplement to* § 11)

THE PROBLEM of the temporal evolution of the Universe leads us into quite another domain of the philosophy of nature than that of its extension or spatiality. In some popular works on astronomy, the problem is, of course, quite simply represented. Astrophysics distinguishes between two separate stages in the evolution of the stars, and considers that the fixed stars came into existence through the condensation of cosmic, nebular masses; and that, in this way, brightly glowing gaseous spheres and suns were formed, which gradually solidified and cooled—a development that is manifested in the fact that the white light emitted from them first becomes more and more yellow, then reddish, and finally, is extinguished altogether. The fact that the stars undergo such evolutionary processes may be regarded as a certainty; but the question still arises: whence came the original gaseous nebulae? The most satisfactory hypothesis would appear to be that the cooled-down heavenly bodies are in some way re-converted into nebulae once more—in which case, all evolution in the Universe would be an eternal cycle, from nebula to star, and from star to nebula. But it is very difficult to formulate an hypothesis, in conformity with physical laws, which explains how the conversion of solid bodies into nebulae takes place. And even if, in agreement with a number of scientists, we were to assume that some chance collision of two of these bodies caused them both, as a consequence of

the heat resulting from the collision, to evaporate and become gaseous, there still remains the question as to whether an event of this kind could be repeated an indefinite number of times, and whether cosmic evolution can really be regarded as a cyclic process of the kind. One definite law seems to confute such an hypothesis—namely, the Law of Entropy, or the "Law of the increase of entropy", which is also known as the Second Principle of the Theory of Heat (the First Principle is the principle of energy).

The law of entropy is quite a new type of principle as compared with the others that we have discussed; and for more than one reason, it merits philosophical consideration.

If the principle of energy disclaimed the possibility of energy being created out of nothing, the principle of entropy denies the possibility of energies being transformed into one another to an arbitrary extent. According to this principle, the energy of heat can only be converted into work under definite and special conditions; while the conversion of other types of energy into heat takes place without qualification. The result is that all energy in the Universe is being continuously converted into heat which can never be completely reconverted into work again.

In the cosmic process that we have just described, heat would have to be increasingly produced at the expense of the kinetic energy of stellar motions: each repetition of the process of star formation would take place with less energy, and would finally cease altogether. The general inference from the principle of entropy, is that the Universe will die a "heat-death" —that is to say, that it will arrive at a state in which,

through the equalization of all differences of temperature, the total energy will be converted into heat from which form it can never again be liberated. In this case, all cosmic events and processes would come to a standstill—everything would be dissolved into that vibrating motion which we know as heat. The attempt has been made to deduce from this a "beginning" as well as an "end" of the world; and the result is a whole series of speculations which incite the philosopher of nature to examine more closely the law or principle of entropy.

In the first place, it may be said that the facts denoted by the principle of entropy prohibit the contemplation of world events in the simple way that we described above—namely, as an alternating cycle of nebulae and stars, and vice versa. In reality, the evolutionary processes of the Cosmos are far more complicated. On the other hand, however, our present knowledge and conceptions of the second principle would seem to indicate that it is not incompatible with the cyclic nature of cosmic events as a whole. But this would not be the case if the principle of entropy were in reality a strict law of nature of universal validity. For in that case, the cosmic processes would be irreversible, and one definite direction of events would be distinguished as possible, while the opposite direction would be impossible. Nevertheless, the investigations made by Ludwig Boltzmann, have given us reason to believe—and this conviction is predominant in contemporary science—that the law of entropy is not a necessary law, but has only a *probable* validity.

In other words, cosmic events do not invariably take place in the way decreed by the principle of

entropy, but only, on an average, in the greater preponderance of cases. When this principle asserts, for instance, that "in the case of the contact of two bodies of different temperatures, heat passes from the warmer to the cooler body, but not in the reverse direction", this statement is true in the same sense in which the assertion: "If playing with normal dice, no one will ever throw a six, a million times running", is true. Now, although this millionfold repetition is not in contradiction with any natural law, we are right not to expect it to occur. According to Boltzmann's reflections, although the probability of an event which takes place in contradiction to the law of entropy, is never equal to zero, it is usually much smaller than in a case like that of the dice mentioned above. Hence, we are still in agreement with physical data depending on the law of entropy when we ascribe to the latter only a very high degree of probability (in some cases, a probability which can be numerically determined), instead of declaring it to be a strict law of nature.

Since the principle of entropy is only a law of probability and can therefore include contradictory processes, such processes must occur—even though very rarely. And the longer the lapse of time, the greater is the probability of their occurrence. Now, since the Universe has indefinitely long periods of time at its disposal, no state of the world exists which cannot—theoretically speaking—be repeated or be reversible. Hence, if somehing like a heat death were to occur once in the Universe, a new differentiation of the universal undifferentiated state, and a conversion of the heat that is uniformly distributed everywhere into other forms of energy, must automatically (by

"chance") occur again. And then, all natural processes would take place in the reverse order, or direction, to that which we are accustomed to experience in the present state of the Cosmos. Thus, all cosmological speculations based on the law of entropy as an absolutely valid law of nature, are untenable.—For the moment, this statement is sufficient for our purpose, and the consideration of whether the aforementioned speculations are not too weak to be justified even if the hypothesis were maintained, is thus superfluous.

The distinction of the *time direction* from past to future—that is, the curious fact that the direction from earlier to later is completely different from the opposite direction with which it cannot, apparently, be exchanged—is unquestionably connected with the unilateral course of natural processes which is in turn conditioned by the "second principle". Or rather: the irreversibility of processes and the unilateral quality of time-direction are, after all, one and the same—a fact to which Boltzmann already drew attention. If all processes in the world, or in a part of the world, were once to run counter to the law of entropy, then past and future would have changed their rôles at that point, and we could say then that temporal progress itself is reversed. Perhaps such a state of affairs would seem extraordinary to us if we lived in it or were transported into it—it might seem to us like a film running backwards. But on the other hand, it is also possible that we should not be aware of it at all, and should continue to believe ourselves to be living in the ordinary world. For it is obvious that what we call "past events" are those of which we have "memory-

images"; and "future events", those of which we have no knowledge. Memory is, after all, the sole criterion that we possess; and it is only a subjective one. So that the question as to which events "objectively" and in reality "precede" others, is something of which we could form no judgment. Indeed, the question as to whether that which appears to us as "past" is really "past" or is perhaps "future" and only seems to us, illusorily, to be past by virtue of the reversed course of all processes (to which our memory also belongs), may be devoid of all meaning.

Reflections like these at least teach us that it is only with the assistance of very special precautionary measures or presumptions, that we can distinguish between "forwards" and "backwards" in the development of events, or ascribe to the time direction an objective meaning.—But the further pursuit of this idea would be epistemological in character and would no longer belong in the domain of the philosophy of nature.

On the other hand, we should like to discuss one question which lies on this side of the frontier of epistemological territory; and that is the problem of how it happens that, generally speaking, we only have exact knowledge of past and not of future occurrences. It has sometimes been suggested that the explanation of this fact can only be discovered in the law of entropy; and this must obviously be the case, since only this principle supplies us with a reason for the doubtful distinction. As a matter of fact, in the case of reversible natural processes in which no perceptible heat is created, and consequently the law of entropy plays no part—as in the motions of the celestial bodies—the

future can be just as easily inferred as the past. But about the subject as a whole, there is no clarity.

Actually, it might be expected that the future—with the help of the principle of entropy—would be much easier to calculate than the past; inasmuch as it is obviously much easier to specify the undifferentiated state towards which a state of irregular distribution is striving, than to specify the more intensely differentiated states from which a less differentiated state has developed. The paradox is resolved if we take into consideration the fact that the structure of the past is inferred from the spatial configuration of objects, and not from the degree of energy distribution. Past events can be recognized and reconstructed because they leave "traces" behind. I can look at the seashore and perceive that shortly beforehand, it had been trodden by a human being; but I cannot perceive from it whether, in the near future, a human being will walk on it. The creation of "traces" in the widest sense, always occurs in such a way that energy in differentiated form (in our case, the kinetic energy of the foot motions of the human being) causes a re-arrangement of the material particles (the grains of sand on the seashore) and imprints upon them a definite shape (the footprint) which persists because, according to the law of entropy, the energy is converted into a dispersed form (irregular motion of the molecules of the grain of sand), and hence causes no further change in the position of the coarser particles. If the energy were to remain in a regular form (as kinetic energy of the grains), the grains, after receiving the footprint, would not persist in a state of rest—and thus no traces would be left behind.— Since our "memory" is unquestion-

ably based on certain traces left behind in the brain, the explanation given here is generally true and makes it plausible that our recollection should only refer to the past (as defined with the help of the second principle) and not to the future.

NOTES

Notes to Preface

1. Preface to Schlick's "Gesammelte Aufsätze" Vienna 1938, p. XXV.
2. Berlin 1925, 2nd edition, p. 367.
3. "Die Philosophie in ihren einzelnen Gebieten", Berlin o.J. (1925), Vol. II, pp. 393-492.
4. Tractatus Logico-Philosophicus, London 1922, p. 76.

Notes to Main Text

1. These sentences—as Schlick himself explained in detail in his lectures—are directed against views similar to those of Heinrich Rickert (1863-1936) as expressed in his book: "Die Grenzen der naturwissenschaftlichen Begriffsbildung" (Freiburg 1896).
2. On the statement of other units of measurement, see p. 27f.
3. See Moritz Schlick: "Raum und Zeit in der gegenwärtigen Physik", 2nd edition, Berlin 1919, pp. 64-73.
4. As a result of the most recent developments in astronomy and astrophysics, this view is once more held in question and in consequence, the following sentence has lost its conclusiveness.
5. This means that the problem of the origin of the world has no clear significance. The sole task of science is to investigate how things originate, develop, or evolve,—and cease to exist.
6. In view of the present developments in nuclear physics, this enumeration of the elementary particles must be regarded as incomplete. But its completion is immaterial, as far as Schlick's argument is concerned.
7. 1 parsec = 3.26 light years; 1 mega-parsec = 1 million parsecs.
8. This whole argument depends to an essential degree on the legiti-

macy of regarding the displacement of spectral lines as a Doppler effect.

9. Schlick expressed his views on this subject in detail, in his "Allgemeine Erkenntnislehre" (2nd edition, Berlin 1925). He planned a thorough revision of this work which he considered to be in some respect obsolete.
10. See "Necessity and Force" in the appendix of this book, p. 88ff; further: "Erleben, Erkennen, Metaphysik" in Schlick's "Gesammelte Aufsätze" Vienna, 1938.
11. This reference justifies the editors' addition to the manuscript of a section on biology which although not originally included in it, was discovered in earlier lecture notes and transcriptions.
12. Although this sentence is not included in the manuscript, it was dictated by Schlick in his lectures of 1936.
13. See the subsequent observations concerning "Conventionalism" on p. 48ff; and Schlick's essay: "Sind die Naturgesetze Konventionen?", (Gesammelte Aufsätze, Vienna 1938; also reproduced in "Gesetz, Kausalität und Wahrscheinlichkeit" Vienna 1948).
14. See Appendix, p. 94ff (The concept of the atom).
15. Those which—according to a terminology used elesewhere by Schlick —"are intersensually and interpersonally verifiable".
16. On account of the ease with which it can be reproduced, the wave length of the red line in the spectrum of cadmium may be chosen as the unit of length.
17. See Rudolf Carnap's brochure: "Physikalische Begriffsbildung", in the series "Wissen und Wirken", Karlsruhe 1926.
18. See "Raum und Zeit in der gegenwärtigen Physik" by Moritz Schlick, Berlin 1917. (4th edition, 1922).
19. The concept of "genetic-identity" was introduced by Kurt Lewin in his book: "Der Begriff der Genese in Physik, Biologie und Entwicklungsgeschichte. Eine Untersuchung zur vergleichenden Wissenschaftslehre", published in 1922 by Springer in Berlin.
20. Here, Schlick unquestionably alludes to the work of Lukasiewicz—"Ueber den Satz des Widerspruches bei Aristoteles" (Bull. de l'Acad. de Sciences a Cracovie, 1909), for example.
21. Compare: "The temporal evolution of the Universe" (Appendix to this book, p. 120ff).
22. L. de Broglie: Voies anciennes et perspectives nouvelles en theorie de lumière. Revue de Met. et de Morale. 41 (1934).
23. From Schlick's "Naturphilosophie" in the "Lehrbuch der Philosophie", edited by Dessoir. Vol II: Die Philosophie in ihren einzelnen Gebieten, Berlin o.J. (1925) pp. 434-437.—Since the parts which are reproduced

in the following sections include references to chapters that are not published here, certain unimportant changes in the text were necessary.

24. See pp. 406-422.
25. Contemporary research provides for a "dispersed radiation" through the unification of a pair of electrons consisting of one positive and one negative component.
26. Braunschweig, 1919, 3rd edition 1922.
27. Arthur Haas: Einfuhrung in die theoretische Physik, Leipzig 1919-21, 5th and 6th editions, Berlin 1930.
28. See pp. 451-456.

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